# Player Interaction Patterns and Objective Types and their Effects on Mathematics Learning in a College Remedial Pre-Calculus Class

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# Chapter 1 – Overview of the Study

## *Introduction*

Performance of United States mathematics students in the past decade has been mixed. Although eighth grade U.S. students showed improvement over low 1996 Trends in International Mathematics and Science Study (TIMSS) scores in the 2003 TIMSS, with no significant deficiencies in mathematical knowledge, application, or reasoning (Mullis, Martin & Foy, 2005, pp 12, 57), in the 2003 Program for International Student Assessment (PISA) "U.S. 15-year-olds scored lower, on average, than their peers elsewhere in both math literacy and problem solving." (Ezarik, 2005, p 72). This is worrying, because the PISA is designed "to establish how well students can develop and apply mathematical models to deal with real-life tasks and interpret, validate and communicate the results." Both the TIMSS and PISA studies place U.S. mathematical and science achievement closer to average than to the top of the scale when compared to students internationally. Yet science and technology form an important core of the U.S. economy, and enrollment in mathematics and science college programs is not keeping up with anticipated workforce demand (National Science Board. 2006).

Meanwhile, there is a growing body of research to support the positive effects of contextualized learning in mathematics (for a review, see Cordova & Lepper, 1996). One way to provide this context is in the form of mathematical learning games (Ibidem). As we will see in a review of the literature, learning games can provide context for learning, simplification of related but non-critical subject areas, a safe learning environment, social interaction opportunities between students, and (especially important from an affective point of view) fun. Bright, Harvey, and Wheeler, in their comprehensive study of mathematical learning games at different instructional points and taxonomic levels (1985) have emphasized the need for further study of high level learning games to determine what elements make them effective. This study aims to explore this area within the realm of pre-calculus mathematical topics.

There are many aspects of games which could be examined for effect on learning. For example, Cordova and Lepper studied the effects of fantasy, personalization, and self-determination in their game designs (1996). This study will examine two different aspects of game design: player interaction formats and objective types, in terms of their effects on learning and attitudes, and possible interactions between them.

### *Research Questions*

This study will focus on two related research questions:

1. How do different game parameters such as player interaction and objective type affect mathematical learning?
2. How do different game parameters such as player interaction and objective type affect student attitudes towards mathematics?

### *Theoretical Rationale*

Although games have often been used as experimental tasks during research (e.g. Jeeves, 1971 and Liebeck, 1990), and attempts have been made to define mathematics itself as a game or as a competitive sport or past-time (Erfurt, 1976, Rabijewska & Trad, 1985, Chapman, 1997), researchers for the past three decades have also strongly noted the potential cognitive advantages of learning games. Games “lead students to *draw various* *patterns* and use them in *the discovery of strategies*." (Bastier, 1969), presenting discovery opportunities (O'Brien, 1976). Mathematical games can encourage the development of problem-solving heuristics (Kraus, 1982). Games can provide "powerful tasks" encouraging reflection during the mathematics learning process (Krainer, 1993), and allow students to exercise the intuition they use in "everyday life" to acquire mathematical concepts such as negative numbers (Linchevski & Williams, 1999).

Games have formed their own part of constructivist reform efforts in mathematics education (Pirie & Kieren, 1992, Steffe & Wiegel, 1992). This use of games, unfortunately, has not always been as effective or consistent as we might hope. For example, Cohen (1990) studied the in-class activities of one teacher and found that though she described herself as "converted" to constructivism, her actual use of new teaching elements such as learning games was limited and not always effective. Researchers such as Cruickshank & Telfer (1980) have offered guidance to teachers with regards to when and how to use games and simulations in classrooms, including considerations related to distribution of status roles, team groups, and teacher participation, and practitioners such as Jaime Escalante have shared their own practical experiences in using games (Escalante & Dirmann, 1990), but this guidance has perhaps not yet been fully absorbed into the culture of mathematics education.

Few theories have yet been developed regarding the effects on learning of the parameters of games themselves. "Ludology," or the science of game design, is a new and growing field, and abstractions of game design theory are just beginning to coalesce. The time seems ripe to use the developing theories of game designers to examine in greater detail the effects of different types of games on the learning process.

### *Significance of the Study*

Student achievement in mathematics seems a perennial concern. As noted above, TIMMS, PISA, and similar scores are watched with care. This is understandable. Mathematics forms the foundation on which science and engineering disciplines are based, and science and engineering based research and development "is of particular importance to both the [U.S] economy and the advancement of knowledge" (National Science Board. 2006 3-17). The number of workers in science and engineering is increasing at a rate approximately four times that of the average annual rate for the whole workforce older than age 18 (National Science Board. 2006, 3-7).

However, enrollments in natural sciences and engineering degree programs (including mathematics) have not always been able to keep up with the demand. Graduates in advanced degrees in the natural sciences and engineering actually declined in the late 1990s and early 2000s in the United States, the United Kingdom, and Germany, before rebounding in the U.S. in 2003. But this rebound was due in large part to doctorates earned by temporary U.S. residents, many of whom may not be willing or able to stay in the U.S. (National Science Board. 2006, 2-4). And regardless of these increases, "In all broad categories of S&E fields, employment in the occupations directly associated with the field has grown faster than new degree production" (National Science Board. 2006, 3-7). The NSB warns, "Slowing of the science and engineering labor force growth would be a fundamental change for the U.S. economy, possibly affecting both technological change and economic growth" (National Science Board. 2006, p. 3-39).

There are many factors potentially inhibiting the mathematical success of students in science and engineering programs—and even fields outside of these areas. Serge Herzog (2005) provides a review of overall college retention which includes both positive and negative factors, such as financial support, prior mathematical background, and affective issues such as feeling one is doing "at least as well as one's classmates." However, majoring in a field requiring higher-level math and passing a first-year math course (or enrolling in higher-level math based on placement scores) were both identified as positive factors toward retention, especially after the second year (p 905). Nevertheless, "being in need of math remediation has emerged as a dropout and transfer-out risk" (p 911). Somehow, helping students succeed in that first year of college-level mathematics is critical.

## *Research Design*

At the University of New Hampshire, MATH 418 is a remedial class offered to students who are not able to demonstrate preparedness for the introductory differential calculus course (MATH 425) based on an established pretest. The sample of students for this study will be drawn from those enrolled in MATH 418.

Two aspects of game design will be examined in a 2x2 factorial design, with a no-treatment (traditional recitation) control group. The two aspects of game design to be examined are cooperative vs. competitive player interaction formats, and exploration/solution (puzzle) vs. construction/solution (simulation) objective types. Each game will be designed by the researcher to incorporate a set of algebra topics chosen from the UNH MATH 418 syllabus. The games will be played during one of the recitation sessions for each of four sections of MATH 418 during the weeks which cover the topics included in the games. Half the students will play each game in a team-based cooperative format, while the other half will play in an isolate competitive format. (An anonymous score board will be used to provide the competitive element.)

A mixed-mode study is proposed. Qualitative elements including a comparative case study involving videotaped observations and interviews with select participants in the treatment groups and an open-ended survey of all students in both treatment and control groups will be combined with quantitative measures of short-term and long-term achievement comparing treatment and control groups. The qualitative components are meant to develop a detailed description of student responses to the game types proposed. The quantitative elements are intended to demonstrate that the effectiveness of the learning games used has been at least as effective as the “traditional” recitation format.

### *Limitations of the Study*

This study is subject to a number of limitations. One key limitation is the small number of parameters of games being examined in this study (two), and the small number of variations of each (also two). It is hoped that the detailed descriptions gathered in this study will serve to establish whether further examination of these parameters is warranted.

The study also does not take into account numerous other factors which may affect students’ mathematical achievement. Some interest in mathematics or science may perhaps be presumed because students wishing to take introductory calculus are usually enrolled in the College of Engineering and Physical Sciences, and are intending to pursue a career in mathematics, the physical sciences, or engineering. However, students may select majors for a variety of reasons, not all of which involve intrinsic interest in the subject matter. A baseline of prior mathematical preparation is established by the factors that the students have been admitted to the university but have not successfully passed the prerequisite test required to advance to the introductory calculus course, but detailed information about prior mathematical preparation will not be taken into account. Also unavailable will be student socio-economic status information, details of other aspects of college life (e.g. on-campus vs. off-campus housing), or employment during the school year. Detailed interviews or surveys may reveal some of this information, and patterns may be noted in the final analysis, but these factors are not the focus of this study.

This study will also be specific to undergraduate mathematics students, and possibly to undergraduate mathematics students intending a career in the natural sciences or engineering. Applicability of findings to other age groups or students with other career interests cannot be assumed.

Finally, because the study involves human subjects and must rely on volunteer participation, some self-selection toward students already predisposed toward learning via games must be suspected. Again, interviews and surveys can attempt to identify this bias and it can be discussed with the findings.

## *Definitions of Terms*

### Game

The definition of "game" itself is somewhat problematic, with different researchers emphasizing different characteristics (Salen and Zimmerman, p79), but

Bright et al, after reviewing a variety of game-related research, focused on the following seven elements:

1. A game is *freely engaged* in.
2. A game is a *challenge* against a task or an opponent.
3. A game is *governed* by a definite set of rules. The rules describe all of the procedures for playing the game, including goals sought; in particular, the rules are *structured* so that once a player's turn comes to an end, that player is not permitted to retract or to exchange for another move the move made during that turn.
4. *Psychologically*, a game is an arbitrary situation *clearly delimited* in time and space from real-life activity.
5. *Socially*, the events of the game situation are considered in and of themselves to be of *minimal importance*.
6. A game has a *finite state-space* (Nilsson, 1971). The exact states reached during play of the game are *not* known prior to beginning of play.
7. A game *ends* after a finite number of moves within the state-space.

(Bright et al, 1985, p. 5).

## Game Design Parameters

Game designers have identified a number of different parameters of game systems. These parameters or elements may be roughly divided into two categories: "formal" and "dramatic" (Fullerton, Swain, & Hoffman, 2004, ch 3-4). Formal elements include players, objectives, procedures, rules, resources, conflict, boundaries, and outcome. Dramatic elements include challenge, play, premise, character, and dramatic arc. (Other game designers may group elements differently, or may emphasize different elements of game systems. For example, Salen and Zimmerman (2004) analyze games using the three frameworks of rules, play, and culture.)

### Player Interaction Patterns

Player interaction patterns are a subset of the player element. Fullerton et al (2004, ch 3) identify the following:

1. Single player versus game
2. Multiple individual players versus game
3. Player versus player
4. Unilateral competition
5. Multilateral competition
6. Cooperative play
7. Team competition

Other combinations or permutations of these patterns are also possible, but for the purpose of this study, only two will be examined: multiple individual players versus game and cooperative play.

### Objective Types

Again, Fullerton et al (Ibidem) identify the following possible objective types:

1. Capture
2. Chase
3. Race

4. [Spatial] Alignment
5. Rescue/escape
6. Forbidden act
7. Construction
8. Exploration
9. Solution
10. Outwit

Most, if not all games fit more than one of these objective types. For the purpose of this study, two combinations of objective types have been chosen: Construction/Solution and Exploration/Solution. (Any game based on algebra topics in which the content will be incorporated into the formal system can be presumed to fit the "solution" objective type.)

# Chapter 2 - Review of Related Literature

## *A Review of the Use of Learning Games*

The use of games to promote learning is widespread in contemporary Western education systems, and is described at length in references such as Silberg (2004). Although there is a lingering tendency for some to think of educational games as “fun breaks” from learning, increasingly research indicates that this need not be the case. Games can be an integral part of the learning process.

Clark Quinn, author of *Engaging Learning*, notes: “Learning can, and should, be hard fun.” (Quinn, 2005, p. 11) “The evidence is that learning is most effective if it attracts the attention and interest of the learner, is obviously relevant, requires action on the part of the learner, and is contextualized so that the learner understands how and when to apply it.” He later continues (p. 15), “Games for learning are not just a guilty pleasure! The evidence is clear that rich environments and story lines are more engaging and more effective.” Quinn quotes Lepper & Cordova, 1992: “adding story enhancements to mathematics instruction improved outcomes.” (p. 12) He then continues:

> To put it another way, we need learning experiences that provide interesting goals set in meaningful contexts in which learners explore and act to solve problems that are pitched at the right level. Their actions should result in meaningful feedback from the world about the consequences of those actions. Further, the learning experiences should gradually increase in difficulty until learners have achieved the final level of performance and accomplished the goal. (p. 37)

In a very real sense, games are all about learning. Ralph Koster explains this quite compellingly in his *A Theory of Fun for Game Design* (Koster, 2005). Games that are too easy are boring, but so are games that are too difficult. Games that are at just the right level of difficulty are full of "learning moments," when the player or players are just able to demonstrate mastery of the game content. At this point the game is the most fun, and we can take advantage of these learning moments to teach, by making the rules and strategy of the game reflect learning objectives. James Paul Gee also emphasizes the engaging aspects of games in learning. "...learning is or should be both frustrating and life enhancing. The key is finding ways to make hard things life enhancing so that people keep going and don't fall back on learning and thinking only what is simple and easy." (Gee, 2003, p. 6) Gee offers a list of 36 learning principles in the appendix (p. 207-212) e.g. #11: "Achievement Principle: For learners of all levels of skill there are intrinsic rewards from the beginning, customized to each learner's level, effort, and growing mastery and signaling the learner's ongoing achievements."

Stott addresses similar topics in a more scholarly treatment. He defines the advantages of "play" (by which he means "structured play," or games) as continuous micro-reinforcement, safe opportunity for practice, extended attention span, and an emphasis on effectiveness-motivation. (Effectiveness-motivation is a more technical way of defining Koster's idea of fun as learning.) Stott also covers the cognitive advantages of learning games, as well as giving practical guidance on learning game design and tactical considerations for classroom use (Stott, 1978).

Games are often a scaled-down version of some part of reality. The classic games

Chess and Go simplify battlefield tactics, for example. Another way of saying this is that "a game has a *finite state-space"* (Nilsson, 1971). This simplification allows learners to concentrate on a specific topic or area without having to consider all related topics in as much detail. In a mathematical game, the teacher can choose a subset of mathematical concepts to focus on, or restrict the context of the problems, allowing students to tackle learning one topic at a time. This further helps to build student confidence by providing useful contexts in which to practice areas of mathematics without becoming overwhelmed by having to deal with the entire domain at once.

### *The Study of Mathematical Learning Games and their Effects on Learning*

The systematic study of mathematics-specific learning games developed momentum in the early 1970's. Devries & Edwards (1973) began their analysis of learning games with efforts to measure the effects of learning games and team settings on classroom process. Bright, Harvey & Wheeler followed this research with a series of studies which used games to retrain skills in basic multiplication facts (1979), and further explicated methods of incorporating instructional objectives into game designs (1979b). They went on to study using games to maintain basic multiplication facts (1980) before culminating their studies in a comprehensive review of mathematical learning games across the range of Bloom's Taxonomy and incorporating pre-instructional, co-instructional, and post-instructional games (1985).

Many specific mathematical games designed to teach particular topics have also been described and studied. In one of the earliest examples, Steiner & Kaufman (1969) proposed using checkers-based games in teaching algebra. A method of making a game out of students generating new problems which use the same principles as a problem they have been previously set was proposed by Wittmann (1971), followed by another approach to algebraic concepts using a card game based on the symmetric group $S_4$ (Hahn, 1975). Dukes (1987) explored the teaching of statistics with non-simulation games. A scrabble-like numerical game was proposed by Bell in 1993, while Shillor & Egan explored problem solving using games in the same year. The past decade has continued this trend, with mathematical modeling (Powell, Cangelosi & Harris, 1998) and Cantor's Theorem (Gueron, 2001) each suggesting their own variations of learning games.

At the same time, the past two decades have also seen an emphasis on computer-based microworlds and games set in these environments. Kraus explored using a computer game to reinforce skills in addition basic facts in 1981, just as microcomputers were first becoming widely available. Earnest followed in 1986 with a computer game designed to teach transformation geometry, and by the end of the decade the interest in Instructional Tutoring Systems had become well established and Hennesy et al wrote on such a system incorporating a "Shopping on Mars" game in 1989. Edwards followed up on the work of Earnest in 1991, using a microworld approach to transformation geometry, and by 1992 Hoyles & Noss were publishing a pedagogy for mathematical microworlds. Clements et al further explored student learning in Logo-based microworld environments in 1996 and 1997.

Game design itself has also been studied as a learning activity. As early as 1973, Goodman explored the cognitive advantages of designing games in addition to playing them or even being a spectator. In 2001, two studies were released focusing on game design as a learning activity. Upitis explored the relationships between young male and female students in the use of games, including learning games, and the processes each group of students used in designing their own games. Noss, meanwhile, wrote on "The Playground Project," in which children were given tools and instruction allowing them to design their own video games.

After providing a comprehensive review of research in mathematical learning games to that point and then describing in detail a thorough study of the effectiveness of learning games at different taxonomical levels and times with respect to instruction, Bright et al noted in 1985 that games could replace drills of low-order objectives, and could also be used by teachers with limited instructional time to extend instruction into higher order objectives. The University of Chicago has implemented this finding in *the Everyday Mathematics* curriculum program, as described in this FAQ:

"Games are an integral part of the program. *Everyday Mathematics* games are not time-killers or rewards, but are engaging activities designed to motivate children to practice a variety of skills. Used on a regular and consistent basis, *Everyday Mathematics* games will satisfy most, if not all, standard drill objectives as well as reinforce a number of skills including calculator skills, money exchange skills, logic, geometric intuition, and intuition about probability and chance. If you skip the games you omit essential practice, especially basic facts practice." (http://everydaymath.uchicago.edu/educators/faqs.shtml)

But Bright et al also suggested, "...more investigation of the use of games to teach higher level content is needed. It is clear that some games are effective in teaching higher level content, but it is not clear why those games are effective." (p. 131) Surprisingly, few researchers seem to have taken up this challenge.

There have been some general investigations in the area of elements of effective learning games. "adding story enhancements to mathematics instruction improved outcomes" (Lepper & Cordova, 1992).

### *Effects of Learning Games on Attitudes*

Learning can be intimidating, and many learners are sensitive to criticism or are afraid of failing to perform correctly. Games offer learners a chance to practice what they are learning in a "safe" environment (Stott, 1978). Learners generally understand that a game offers a chance to try new skills with the understanding that they might not be completely successful right away. American culture is full of expressions such as "it's not whether you win or lose, but how you play the game," and as teachers we can take advantage of this special feature of games to help our students overcome their fears of "looking silly" while they are learning mathematical skills. Bright et al note that "*Psychologically*, a game is an arbitrary situation *clearly delimited* in time and space from real-life activity. *Socially*, the events of the game situation are considered in and of themselves to be of *minimal importance*." (Bright et al, 1985, p. 5)

In addition, many learners, especially children, learn best when they are able to learn with a group. Students help each other and offer emotional support through the learning process. In particular, there is a new emphasis in mathematics teaching on communication that requires students to practice this communication to effectively build mathematical concepts and communication skills. Because many games involve multiple players, such games allow students to use language to cooperate with each other and to rely on social skills to help them learn.

Games can provide motivation and energy to learners. Learning mathematics can be difficult and frustrating, and students can easily lose focus and have difficulty staying engaged in the learning process. Games provide a way for learners to keep their interest level up and focus on the learning objectives (Stott, 1978). While this motivational factor should not be the only reason for adding a game to a lesson plan, it is a powerful advantage which should not be overlooked.

Instructional games can help reduce absenteeism, allowing for more time spent in learning (Allen & Main, 1976). Mathematical games can also help to alleviate the widespread problem of "mathophobia," as Resek and Rupley note that in their program to eliminate fear of math: "Each student is required to play for fifteen minutes a week in a math lab that contains mathematical games and puzzles, games on programmable calculators, and games on microcomputers. Students work on easier games and puzzles in a seemingly non-mathematical environment, thus acquiring good practice with reasoning tasks. Many of them are less fearful in this environment than when they have worked on standard mathematical problems in more traditional environments." (Resek & Rupley, 1980, 427-428)

One persistent caution is that games not be used frivolously or ineffectively, as many "fun" elements have been in the past (e.g. Moyer, 2001). Game elements which distract from learning objectives or which offer equally interesting experiences whether the learning objectives are achieved or not can actually impair learning.

## *Aspects of games and their effects on learning and attitudes*

### Player Interaction Patterns

Competition is often offered as one of the motivating factors of games. However, one caveat is the need to ensure that learning games do not encourage destructive levels of competition. Kaplan et al. address the potential negative impact of “performance” goal orientation, in which learners perceive each other as competitors for grades, teachers’ attention, and other resources. Instructional practices which emphasize competition and public comparison of performance can weaken student self-esteem and lower long-term achievement (Midgley et al, 1998, 2000).

Fortunately, many game formats have been devised which are principally or entirely cooperative, including the venerable “jigsaw” exercise, which was designed specifically to counter competition in the classroom (Aronson, 2004). Sapon-Shevin (1978) offers an excellent analysis of the effects of competitive games on students as well as comprehensive guidance on how to design effective cooperative games.

As part of this study, each game will be played in two formats, one competitive and one cooperative. Negative effects of the competitive format will be mitigated by making the score board anonymous, so that players can see where they stand in the group overall, but cannot directly compare themselves to specific other players.

### Objectives

For the purpose of this study, two combinations of objective types have been chosen: Construction/Solution and Exploration/Solution.

The Construction/Solution (simulation) format takes advantage of the immediate feedback feature of games, by providing an environment in which correct use of the algebraic skills has immediate and visible consequences to the player or players. The Exploration/Solution (puzzle) format takes advantage of the attraction of “mystery” in a game, encouraging the creative use of the algebraic concepts in solving a series of puzzles.

# Chapter 3 – Research Design

## *Introduction*

At the University of New Hampshire, MATH 418 is a remedial class offered to students who are not able to demonstrate preparedness for the introductory differential calculus course (MATH 425) based on an established pretest. Students who enroll in MATH 418 are generally majors in the College of Engineering and Physical Sciences, and most will continue on to enroll in MATH 425. Many will also enroll in courses such as PHYS 407, an introductory physics course which uses many of the same mathematical skills and which requires MATH 425 as a pre- or co-requisite.

## *Research Questions*

This study hopes to address the following two research questions:

1. How do different game parameters such as player interaction and objective type affect mathematical learning?
2. How do different game parameters such as player interaction and objective type affect student attitudes towards mathematics?

## *Research Design*

A qualitative comparative case study will form the central component of the study. The comparative case study was chosen to highlight the similarities and differences between the experiences of learners experiencing different game design types (Merriam, 1988). The qualitative data in each case will be partially corroborated by select quantitative assessments.

The comparative case study will be preceded by a preliminary written survey, which will be used to identify possible case study participants as well as to build the initial conceptual model. A more detailed, anonymous written survey will follow to begin the process of generalizing the findings to a wider population.

Results will be evaluated to compare the treatment group with the control group in several ways, including the performance in MATH 418 exams, a before-after affective survey evaluating learner perception of their comfort with math in general and the pre-calculus subject material in particular, and follow-up performance both MATH 425 and PHYS 407. Because MATH 425 and PHYS 407 are both large-section courses, both experimental and control groups should receive similar instruction in these courses.

## *Research Methodology*

### Preliminary Survey

An open-ended survey asking questions related to student attitudes toward mathematics, mathematics-dependent subjects, and learning games will be distributed to at least 20 students enrolled in MATH 418, and 20 students enrolled in MATH 425.

### Game Development

Two games will be developed. The Construction/Solution game will provide a simulation of a situation requiring algebra skills to successfully manage. The proposed topic is the management of resources for a self-sustaining colony on the surface of Mars, based on changing population, environmental factors, etc. The Exploration/Solution game will provide an extended puzzle environment in which the student takes the role of an astronaut explorer who finds the remains of an alien inhabitation, and must decode details of the alien race and its history based on algebraic clues.

### Comparative case study

Elements of the comparative case study portion will include:

1. Pre and Post Survey Comments
2. Observations/Video
3. Interviews

### Quantitative measures of mathematical achievement

Quantitative measures will include:

1. MATH 418 Placement Test
2. MATH 418 Unit Tests and Final Exam
3. MATH 425 Final Exam
4. PHYS 407 Final Exam

## *Sample*

At the University of New Hampshire, MATH 418 is a remedial class offered to students who are not able to demonstrate preparedness for the introductory differential calculus course (MATH 425) based on an established pretest. Students who enroll in MATH 418 are generally majors in the College of Engineering and Physical Sciences, and most will continue on to enroll in MATH 425. Many will also enroll in courses such as PHYS 407, an introductory physics course which uses many of the same mathematical skills and which requires MATH 425 as a pre- or co-requisite.

MATH 418 is offered in multiple formats. One format consists of three weekly lecture meetings and two weekly small recitation sessions. In this study, four sections of

MATH 418 would be modified to replace one recitation session per week with a learning game session for each week in which the algebraic topics included in the game were covered in the syllabus. Two other sections of MATH 418 with the standard recitation arrangement would serve as controls.

## *Pilot Test*

- The initial survey will be piloted against a small group of students from MATH 418 and MATH 425 enrollees, then refined.
- All games need playtesting before study begins
- Initial version of game will be paper-based, though a computerized version might be preferable

## *Data Gathering Procedures*

Interviews will be audio recorded and transcribed. Videotapes of play sessions will not be transcribed, but will be coded using time markings.

## *Method of Data Analysis*

Qualitative data will be coded using an organically developed system, and patterns sought and explored. Quantitative data will be subjected factoral analysis.

## *Formats for Reporting the Data*

Data will be reported as detailed descriptions of student experiences and student learning model diagrams, as well as summary tables of quantitative effectiveness measures.

*Frameworks for Discussing the Findings*

The findings will be discussed in light of the earlier research areas identified, namely:

- Theories or observations about learning games
- Theories or observations about mathematical learning games
- Theories about the effect cooperative vs. competitive play on learning and attitudes toward mathematics
- Theories about the effect of game objective types on learning and attitudes toward mathematics

Confirmations of earlier theories, as well as possible conflicts, will be explored, and recommendations for future research will be suggested.

- The significance and implications of the findings will be examined with respect to:
- The impact of attitudes toward mathematics on learning and achievement
- Implications for mathematical learning game design

Recommendations for the further design and use of mathematical learning games in high school and early undergraduate classes will be proposed.

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