

The Effect of High-Order Learning Games on Problem Solving Ability and Affect Toward Mathematics among College Remedial Pre-Calculus Students

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Abstract: : A study of the use of mathematics games in a pre-calculus remedial mathematics class is proposed. The effects of the game treatment will be evaluated in terms of success in the remedial class, success in the following calculus class, and success in a physics course normally enrolled in by freshman students in the College of Engineering and Physical Sciences simultaneously with calculus. Attitudes toward mathematics will also be assessed.

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. Analyses of the mathematical achievement of incoming college students indicate that these weaknesses seem to continue through high school, affecting many freshman college students (Ellen O’Keefe, October 2007, private communication). 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). 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 motivational support. 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.

Research Question

This study will focus on the following research question: Can high-order learning games in mathematics have a lasting effect on problem-solving ability and affect toward mathematics?

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).

For the purposes of this study, we will adopt the following definition of a “game”: an activity which embodies a simplified or abstract subject in a format which provides constraints, goals and scoring, often including fantasy and mystery elements as well. We will also define *learning games* as games which use scoring to provide integrated feedback on skill accomplishment to learners, and *high-order learning games* as games that emphasize higher levels of Bloom’s Taxonomy (such as Application, Analysis, Evaluation, Synthesis), or, in other terms, procedural and strategic cognitive skills, rather than memorization or even comprehension (e.g. restatement, categorization, etc.)

Theoretical Rationale

Researchers for the past three decades have strongly noted the potential cognitive advantages of learning games in mathematics. 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). Somehow, helping students succeed in that first year of college-level mathematics is critical.

However, as noted above, many students may struggle during that first year, due to a lack of sufficient mathematical preparation to be successful in these courses. Ellen O’Keefe, director of the Mathematics Learning Center, notes: “Prior to the creation of MATH 418, the Math dept offered a noncredit precalculus course, MATH 405. At that time, all MATH 425 students took a pretest, and based on the results of that pretest,

students were told one of three things: (1) you're all set to take calculus; (2) your placement in calculus seems to be the appropriate one, but you have weaknesses on some areas, and you will be required to do review work in those areas at the UNH Mathematics Center; or (3) based on the results of the test, the [Mathematics Department] feels that you need more preparation before you take calculus. We strongly recommend that you take MATH 405 this semester so that you will be ready for MATH 425 next semester. The recommendations were purely advisory, and very few students enrolled in MATH 405. The failure rate in MATH 425 was very high, and people in all CEPS departments were concerned about that. In [Fall 2000] Bob Henry [the Associate Dean of the College of Engineering and Physical Sciences] formed a committee consisting of representatives from various CEPS departments to address the problem, and the creation of MATH 418 (a for-credit precalculus course) came out of that committee. The notion of a mandatory placement test came out of that same committee... The placement test was created by a committee of Math dept faculty, and the placement matrix was created by that same committee. Performance on the test does seem to correlate with performance in subsequent courses...." (Ellen O'Keefe, October 2007, private communication) The new MATH 418 course first started being offered in 2001.

The high failure rate in the first semester calculus course was a critical factor in the development of this program. Yet, "being in need of math remediation has emerged as a dropout and transfer-out risk" (Herzov, 2005, p 911). Is the course serving its purpose of improving success in more advanced CEPS courses? Is the ongoing need for remediation, and the risk of dropout or transfer-out entailed with that need, being addressed? Further analysis is needed, but anecdotally, members of the College of Engineering and Physical Sciences faculty have expressed concerns about the success of the MATH 418 offering, including a concern that the content is too theoretical, and not contextualized enough (Dr. Robert Henry, October 2007, private communication). It would seem that this population represents a good opportunity for an intervention designed to improve both cognitive learning and affective motivation toward mathematics.

Research Design

Only one site, the University of New Hampshire, is proposed for this study. While this presents an undeniable convenience for the implementation of the study, it also improves the internal validity of the study design, by providing a broad consistency across experimental and control groups. There is also a large population present with clearly defined needs who will be available for follow-up. A future direction might be to implement a similar intervention at multiple institutions with roughly comparable remedial mathematics programs.

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 (see Appendix A). The sample of students for this study will be drawn from those enrolled in MATH 418. The sampling method planned is true randomization of students between triplet sections of MATH 418 offered at comparable times, assigned to one of two treatment groups or a control, to avoid scheduling considerations as an obstacle to participation. It is hoped that this method of randomization will be possible due to the high level of support being offered at the department and college level for this study. This design will allow for the strongest interpretation of results, by avoiding issues such as self-selection bias or other unknown biases.

Two treatment programs are proposed: a learning game format, and a problem discussion format.

In the learning game format, 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 the primary treatment sections of MATH 418 during the weeks which cover the topics included in the games.

In the problem discussion format, one recitation section per week in each of the secondary treatment sections will be devoted to small-group discussions of problem sets. This alternative treatment is intended to help eliminate the rival hypothesis that it is the small group interaction format, rather than the games themselves, which leads to the anticipated improvements in problem solving ability.

The primary constructs to be measured are mathematical achievement, particularly in the pre-calculus area, attitude towards mathematics, and mathematical problem solving achievement. A preliminary survey will also attempt to measure experience with and attitude toward games in general and learning games in particular, among both students and instructors, to look for possible interactions.

To measure mathematical achievement, the study will rely primarily on the existing Calculus Placement Test developed by the mathematics department. (For a sample test resembling the actual placement test in level, though not in length or breadth of coverage, please see Appendix A.) This assessment exists in several forms, and while detailed psychometric analysis has not been done on any of the forms, a follow-up study did establish a high correlation between performance on the placement test and subsequent success in both the remedial class and calculus (Gertrud Kraut, private communication). Additional psychometric analyses will be performed on the forms of this placement test in use during the study.

Students who attend the remedial class are usually not administered the placement test on exit, but are administered a separate final exam. If the final exam is equivalent to the placement test, it may serve as an alternate form. This will need to be evaluated. If the final exam is not functioning as an alternate form to the placement test, an alternate form of the placement test will be re-administered to all study participants (primary and secondary treatment groups and the control group) at the end of the remedial course.

Performance during the remedial course will also be measured in the form of quizzes throughout the semester, a mid-term exam, and a final exam. These assessments will provide additional data points of mathematical achievement during the treatment.

In addition, self-reported SAT quantitative scores will be collected from students in treatment and control groups.

Following the treatment, students who enroll in Calculus I (MATH 425) during the subsequent two semesters will be monitored via their quizzes and midterm and final grades. These will be included in the regression model to measure post-study mathematics achievement. (Students who participate in the study but do not enroll in Calculus during the subsequent two semesters will be counted as part of the measurement of attitude towards mathematics, as noted below.)

Attitude towards mathematics will be measured at the beginning and end of the study, using a published instrument such as the Aiken Scale (Aiken, 1974), The Revised Math Attitude Scale (Dutton, 1962), the Mathematics Attitude Inventory (MAI) (Sandman, 1980) or the Fennema-Sherman Mathematics Attitudes Scales (FSMAS). These scales have all been validated with college students of mathematics, but some concerns have been raised about the use of some of the scales (e.g. Tapia & Marsh, 2004). Additional investigation will be required to determine which scale will be the most appropriate for this purpose.

Another component of attitude which will be measured for inclusion is retention in the science and mathematics program. This will be measured by comparing the number of students who enroll in either or both of MATH 425 (calculus) and PHYS 407, the next expected courses in a typical engineering and physical sciences sequence of study after completing the remedial mathematics course, between the treatment and control groups. Retention in CEPS majors may also be measured.

Physics achievement will be used as an estimate of mathematical problem solving achievement. The physics course which will be used to follow-up study participants, PHYS 407, heavily emphasizes use of mathematics to solve simple physical problems. This course requires calculus as a co-requisite or pre-requisite, and depends on the same trigonometric and function skills as are assessed in the mathematics placement test and taught in MATH 418. Physics achievement will be measured using lab, quiz and exam scores in PHYS 407. The lab scores will form a significant component of this study, as they should substantially reflect the problem-solving abilities of the students in a relatively unstructured setting. However, there are other factors involved in successful laboratory work besides mathematical problem-solving ability, so the quizzes administered through the recitation sections, which also focus on problem solving but provide more structure and guidance, should also be helpful in attempting to measure this construct.

No psychometric analyses of the assessments administered by the physics department are available. However, such analyses will be completed as part of this study. The freshman physics program is well-established and the size of the program has

encouraged the use of multiple, relatively well standardized forms of exams and other assessments.

Finally, it is hypothesized that prior experience with games, particularly learning games, may provide an interaction with the treatment. Few published instruments attempt to measure this construct, though there are some attempts to measure the use of computer or video games as both entertainment and as learning tools (e.g. Sanford et al, 2006). A new survey will be designed for this purpose, covering experience with a variety of formats of games, including board, card, computer, and other formats. It is proposed to validate this survey against the population of ENGL 401 (“Freshman English”) students prior to its use in the main study. Items will be developed, forms administered, and the results subject to item analysis and principle component analysis with only the best-performing items retained in the final instrument.

It will also be helpful to measure experience with and attitudes towards games among the instructors of the remedial sessions, in both treatment and control groups. Since the instructors will be administering the games during treatment sessions, their attitudes may positively or negatively affect delivery of the treatment program.

Anticipated Analysis

The degree to which students participate in both treatment groups (based on attendance) will be tracked, but the analysis will treat overall participation as a dichotomous variable, as little variation is expected among those who participate in the experiment, and by definition, no variation is expected among those in the control group.

As this is effectively a longitudinal study with measurements before, during, and after the treatment, multilevel modeling will be used for longitudinal purposes.

Potential instructor effects (mathematics teaching experience and experience with and attitude toward learning games) will be included as terms in the regression model, but will not be addressed by multi-level modeling in this study, due to an insufficient number of instructors.’

Limitations of the Study

This study is subject to a number of limitations. The study does not take into account numerous factors outside of the game treatment 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. Demographic 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.

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