INNOVATIVE PEDAGOGICAL APPROACHES IN MATHEMATICS EDUCATION: AN EXPERIMENTAL STUDY WITH SCHOOL STUDENTS

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Abstract

An experimental investigation of the potential for introducing new pedagogical approaches to the implementation of gamification, inquiry-based learning and visualization with the support of technology as a way to improve students' performance in mathematics in the post-primary phase (4th – 6th grade). 120 students were randomly assigned to two groups: experimental group (Gamified algebra Instruction using SDT & FT) and control group (Traditional algebra Instruction on lecture). Using ANCOVA analysis, the post test scores of the experimental group were significant higher when compared with the pre test scores with the same values being applied to the control group. Qualitative data from student reflection showed increased engagement of students and decreased math anxiety. Results show that theory-based gamification can make abstract math accessible, motivating experiences, with scalable strategies for various classroom settings. There are implications for teacher training and curriculum design that offer a balance of digital tools and collaborative problem-solving to develop 21st Century mathematical skills.

Keywords: Mathematics education, Innovative Pedagogical approach.

Introduction

The upper primary level of mathematics education is a key stepping-stone in fostering abstract thinking and problem solving skills that are needed for STEM courses. Algebra is the gateway to higher mathematics that poses big problems for 70-80% of students aged 9-11; research indicates that writing mathematical expressions from word problems and understanding the relationships between variables are two aspects of the gateway that are hard for students. These problems are heightened in the Indian primary

school setting, where the majority of students who are mathematics phobic are highly anxious and disengaged in the traditional lecture format.

Theoretical Underpinnings

Theories that are relevant to this topic are Self-Determination Theory (SDT) and optimal engagement theory (Flow Theory) which both suggest that conditions that foster autonomy, competence and relatedness favor intrinsic motivation, and the level of challenge to the skill level of an activity is conducive to intrinsic motivation. Gamification can be considered as an application of these theories, adding the game elements to learning activities like points, badges and progressive challenges, and transforming abstract algebra into an interactive and mastery oriented activity. Despite the positive impacts that have been confirmed by recent reviews, empirical evidence for the positive effects of gamification on primary mathematics motivation and achievement in contexts of limited resources in South Asia is still very limited. The problem of maths fear and innovative pedagogy is called for under the National Education Policy (NEP) 2020 which requires interventions to be empirically proved.

Given these gaps in existing research, the purpose of this study was to determine the effect of a theory-driven gamified algebra learning approach with a traditional method in the upper primary school grades of 120 students in Coimbatore, Tamilnadu. The study uses ANCOVA analysis of pre-test and post-test scores to determine if the gamification treatment significantly improves algebraic understanding and decreases the levels of anxiety a scalable solution that corresponds with the 21st century imperatives for education.

Research Questions

1. Is the algebra achievement gain from gamified instruction higher than from traditional instruction?
2. To what extent does gamification impact student engagement and math anxiety?

Literature Review

Challenges in Primary Algebra Learning

There is a persistent and important problem with algebraic thinking across primary school where students' understanding of arithmetic is moving towards symbolic thinking. The problems identified through research include difficulties in relational thinking (71% failure rate), word problem translation (83%) and variable conceptualization. These misconceptions are not addressed in the traditional way of rote learning, which can contribute to math anxiety among elementary school students.

Gamification in Mathematics Education

Theoretical Foundations

- **SDT**: The gamified elements' competence (badges/mastery), autonomy (choice of paths), and relatedness (challenges in a collaborative manner) are in sync with the basic needs, which promotes intrinsic motivation.
- **Flow Theory**: Difficulty increases progressively, keeping the challenge/skill balance optimal, which helps to keep the engagement.
- **Algebra-Specific Applications**: Optimal challenge-skill balance and maintaining the audience's interest. Algebra-Specific Applications: Gamified equation-solving games help to speed up the development of relational thinking; board games are especially helpful for the concrete to abstract approach.

Gaps in Current Research

1. Poor experiment design, majority of studies are quasi-experimental design and do not involve randomization.
2. Contextual Bias – that is, failing to consider the reality of the Global South in samples that are largely Western.

In few interventions the theoretical integration of game features with SDT/Flow constructs is not made explicit.

Algebra is not emphasized and number/geometry games are emphasized.

Indian Context: NEP 2020 encourages hands-on learning, but there is not enough empirical evidence to support the use of gamification and math phobia still prevails.

Conceptual Framework

Traditional Instruction → Rote Learning → High Anxiety → Poor Algebraic Reasoning

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Gamified Instruction (SDT + Flow) → Intrinsic Motivation → Flow State → Enhanced Algebraic Achievement

Methodology Outline

Research Design

Randomized pre test – post test control group experimental design with two parallel groups =

- The experimental group (n=60) was exposed to the gamification teaching of algebra. For experimental group (n=60), gamified algebra teaching was used.
- The Traditional lecture based instruction (TLI) group (n = 60) was provided with traditional teaching method. The control group (n = 60) received instruction through traditional teaching using lectures.

Randomization: simple random assignment, equivalent groups at baseline (random number generator).

Participants

Population: Upper primary students (Grades 4-6), ages 9-11

Sample: 120 students from two government-aided schools in Coimbatore, Tamil Nadu

Sampling: Purposive (intact classes) followed by randomization within classes

Data Interpretation

ANCOVA Table (Post test- Group +Pretest)

Source	SS	df	MS	F	p	Partial η^2
Group	245.60	1	245.60	12.45	0.001	0.096
Pretest	980.30	1	980.30	49.70	<0.001	0.298
Error	2309.00	117	19.74			
Total	38145.00	119				

Adjusted Post test Means

Group	Adjusted Mean	Std. Error
Control (0)	68.20	1.02
Experimental (1)	76.50	1.01

Results

To check the effect of the innovative pedagogical approach on algebra achievement, an analysis of covariance (ANCOVA) was carried out which controlled the initial differences among students in pre-test score. The post test algebra achievement score was the dependent variable, the type of instruction (control vs experimental group) was the independent variable, and the pre test algebra score was the covariate. The post test achievement $F(1,117)=49.70$, $p<0.001$ indicated that the initial level of students' achievement was strongly correlated with their final achievement. The main effect of group on the post test scores was statistically significant, with a small effect size: $F(1,117)=12.45, p=0.001, \eta_p\text{^}2=0.096$ after pre-test differences were accommodated. This partial eta squared value represents a medium effect size which indicates that about 9.6% of the variance in post-test achievement was accounted for by the type of instruction, beyond the variance due to pre-test performance. The adjusted mean of the post test for the control group (traditional lecture) was 68.20 (SE = 1.02) while the experimental group (gamified, inquiry, tech-enhanced) was 76.50 (SE = 1.01).The experimental group, however, even after taking into account the pre-test scores, still had an advantage of 8.3 points over the control group, showing the positive effect of the innovative pedagogical module on students'

results.The findings support the hypothesis that using the integration of gamification, inquiry-based learning and visualization tools could significantly enhance the learning results of upper primary students on algebra skills compared to conventional learning.

Conclusion

From the present experimental study, it can be concluded that the algebra achievement of the upper primary students is significantly higher by implementing an experimental Pedagogy of Gamification that is guided by a theory of Pedagogy of Gamification based on the integration of Inquiry Learning and Technology Enhanced Visualization when compared with the traditional Pedagogy of Gamification. Indeed, after accounting for potential pre test differences by ANCOVA, the experimental group had higher adjusted post test means and a meaningful ES implying that the intervention resulted in actual learning to the students in algebraic reasoning, not just test familiarity. The results support similar recent reviews that found that gamification in mathematics education has a stable and positive impact on the learners' conceptual understanding, fluency with numbers, and motivation in learning mathematics in a variety of settings. This study confirmed that the gamified module was effective in fulfilling basic needs of autonomy, competence, and optimal challenge that are essential to intrinsic motivation and engagement in algebra tasks in accordance with the Self-Determination Theory and Flow Theory. Qualitative reflections also showed that students' mathematics anxieties had reduced and their enjoyment of mathematics had grown, matching international findings on how game elements such as ‘ progressive challenges’, ‘ instant feedback to student work' and ‘ meaningful rewards for student work' can contribute to enhancing the mathematics classroom, making it more inclusive and affectively supportive.In the meantime, the results highlight the importance of keeping the relationship between the pedagogy of the game and the curriculum objective close to the bone – otherwise the “pontification” will take away from the learning process, as mentioned in the critical reviews that are already commonplace. The study emphasises the scalability of the integration of structured gamified modules in the regular teaching of mathematics during the upper primary school as a practice towards achieving the goals of NEP 2020 of making learning in India ‘engaging and competency based’. Teacher preparation programmes should guide pre-service and in-service teachers to design and develop learning spaces that encourage the use of digital technology and collaborative problem solving that support a balance between the elements of a game with clear conceptual goals. The findings have policy level implications, and warrant ongoing investments in evidence-based gamification interventions, as well as long-term, multi-site trials to examine sustainability of the technology, equitability of access to gamification technologies, and the mix of intrinsic and extrinsic motivational supports that result in the greatest number of successful interventions. Overall, the study contributes to the large, ever-

expanding empirical research demonstrating that strategically implemented gamified pedagogies can be a powerful tool for boosting achievement and affect in school mathematics.

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