An empirical investigation into the impact of the first-person role-playing games to improve knowledge retention in middle-school children in India: A pre-post study of the game 'Tattva Bhoomi'

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ABSTRACT

One of the key trends observed in the domain of contemporary education are the attempts to utilize the capabilities of digital games for the enhancement of education. Even though there exists ample data that indicates the positive effects of digital games in the context of education, there still remains a gap in understanding their integration into pedagogy. The few studies conducted and the data generated tend to be borne out of western countries and in India specifically, there appears to be a lack of understanding as to how games could benefit the educational goals and objectives of the students. It also remains a mystery how these games could be integrated into the curriculum and pedagogy. Therefore, this research is an attempt to understand the effectiveness of game-based interventions for the student population of India and how these game-based learning applications could be integrated into the curriculum.

This study tries to gauge the change in knowledge retention of 142 middle-school students by applying a game-based intervention of Tattva Bhoomi, an exploration-based first-person role-playing game. The study investigates a total of three experimental conditions in two different schools through the methodology of pretest, intervention, and posttest. The results are analyzed using a Mann-Whitney U test, and the findings of all three experiments indicate that there is a significant improvement in the performance of the experimental group when compared to the control group and that the change can be attributed to the game-based intervention. The study also reports a comparison between the different experimental conditions and their efficacy.

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Keywords
Design for Education, Game-based Learning, Indian Education, STEM Education, Pedagogy

INTRODUCTION
The employment of game-based applications for the purposes of teaching and learning in the Indian educational context is less common and less researched when compared to western education. This often leads to the adoption of assumptions from the literature on game-based learning, which has been mainly researched in western countries and is applied to the Indian context indiscriminately.

India, however, brings educators a complex set of problems that are distinct from the general educational problems, and, therefore, cannot be addressed by conventional solutions that work in the west. In their paper, De (2019) points out the following problems which might be unique to the Indian educational context: (i) children are enrolled from diverse backgrounds that might be new even for the teachers, (ii) many students have limited or no home support, which demands high levels of training from the teachers (iii) students facing difficulties in accessing the schools, including disability, rarely get the necessary support, (iv) many times, the home language of the students tends to be different from the language of instruction at school, (v) some students come from backgrounds that depend on agriculture and forests, and (vi) vulnerable students may come from hostile home environments and habituate to irregular attendance. The author then points out that it is a necessity of the times to have instructional mediums that promote inclusive and participatory pedagogies instead of encouraging rote learning (De, 2019).

This study, therefore, considers the applicability of using game-based applications to promote and improve the learning process of the Indian student. The study investigates the use and potential of educational computer game-based applications, particularly the first-person role-playing game Tattva Bhoomi in the Indian classroom for increasing learning outcomes, knowledge retention, motivation, and acceptability of the said intervention. This particular paper reports on the short-term knowledge retention of the participants.

LITERATURE REVIEW
Yang (2019), in their paper, titled, “Video games for stem learning: How does it work”, poses and back the idea that there exists strong evidence that endorses the use of digital games as powerful tools for learning when compared to the traditional model of learners taking in information passively. Although they do support the idea that digital games and their multimodal approaches can be harnessed for greatly improved methods of teaching and learning, Yang also concludes with the following questions that future researchers can work on: (i) How can compelling narratives be designed that encourage different types of learning? (ii) How can digital games be seamlessly integrated into the classroom that generally exercises traditional methodologies? (iii) How can balance be struck between the new offerings of video games and the traditional styles of teaching? These questions posed by Yang indicated a wide scope of research that can be focused upon by the current researchers (Yang, 2019, August).

Gaydos and Squire (2012) acknowledge that there has been an increase in the support for employing digital games and simulated environments for science education in recent years (Gaydos & Squire, 2012). The ability of video games to provide a creative route for large-scale STEM education is also acknowledged by Mayo (2009) in their paper published in Science magazine (Mayo, 2009). The president of the United States has also urged researchers to utilise the abilities of digital games to

develop and design better modes and treatments for STEM education (Gibbs 2010). Similarly, the government of India, in their budget for 2022, acknowledges the importance of the gaming industry in the country (Union budget, 2022). The National Research Council concluded that video games are an important factor in catalyzing and improving education through reforms (National Research Council, 2010). The report also states that simulations and games hold the potential to improve learning outcomes, motivation, engagement in science, conceptual representation and understanding, augmentation and science learning and skills. Gaydos and Squire (2012) argue that researchers need to work and ask questions about new meanings that can be made possible through the use of games, instead of just being a mode of content delivery. They urge scholars, developers, and designers to dig into the capabilities of games to bring forth new practices for literacy, new symbolic transformations and social interactions. However, they also remind the reader that these newfound possibilities would need to seamlessly integrate with the traditional practices of education (Gaydos & Squire, 2012).

METHODOLOGY

The overarching methodology of the entire study was the same: (i) segregation of each sample body into a control group and an experimental group, (ii) a pretest for all the participants, which comprised a 14-item questionnaire, (ii) a game-based intervention for the experimental group, and finally (iv) a posttest for all the participants in which the conditions were kept similar to the pretest. However, the implementation of the intervention and the sample group was different for each study. Therefore, the methodology of each experimental condition has been further elaborated in the sections below. The data collected from these three experiments were analyzed using a Mann-Whitney U test, the results of which are described along with each experiment respectively.

QUESTIONNAIRE

The questionnaire was formulated in English and it had questions derived from the class 11 chemistry chapter *Classification of Elements and Periodicity in Properties*, which were also the topics being taught through Tattva Bhoomi. The selection of the material was made to ensure that the students had minimum knowledge about the intervention content. Question 1 required a numerical answer, questions 2, 3, 6, 7, 8, 11, 12, 13, and 14 were multiple-choice questions, questions 4 and 5 required one-word descriptive answers, and questions 9 and 10 required the participant to shade in one of the cells in an empty periodic table. The grading was done as follows: a correct answer was given one mark, a partially correct answer (for descriptive answers) was given half a mark, and a wrong answer was given no marks. The maximum marks one could get were 14. The questionnaire items were formulated using the tutorial by Hinkin (1998), which describes the development of measures for use in survey questionnaires and the BRUSO model generated by Peterson (Hinkin, 1998; Peterson, 2000).

TATTVA BHOOMI

Tattva Bhoomi is an exploration-based first-person role-playing game which puts more emphasis on exploration than on role-play. The game was developed by the researcher for the purposes of this study (Solanki & Mathew, 2022).

Walkthrough of the game

The game commences with a title screen that introduces the player as an explorer on a mission to obtain resources in India. The player can choose from 36 Indian states; however, only Rajasthan is accessible in the early stage. After selecting it, the player is directed to a desert landscape to explore the region. The first scroll collected by the player reveals that they are in the Zawar mines of Rajasthan, which are rich in copper,

silver, and zinc. The game's goal is to collect all metal ores and scrolls to progress to the next level. The player must search for ores and scrolls and collect them. Audio pings and text pop-ups accompany each collection, and the score is updated on the screen. Each scroll unravels to provide information about elements and ores, with the complexity gradually increasing. Upon collecting all ores and scrolls, the player is congratulated and taken to a periodic table screen with all elements greyed out except hydrogen. The player unlocks hydrogen, granting them enhanced abilities to traverse the landscape more quickly and efficiently. The player is also informed about the capabilities, properties, and uses of Hydrogen. The player must then collect everything with these new abilities once again to unlock helium, which allows them to jump higher and reach new heights. The player is informed that this is because Helium is a very light element. The game version ends with 60 ores and 12 scrolls spread across three levels. The information that the player learns in this game is mainly through the ores they collect, the scrolls they read about classification of elements, and through the elements they unlock by completing levels. The entire video play through of the game can be found in the endnotes[1]. Some screen shots of the game are depicted in figure 1, 2, and 3.

Figure 1: Rocky desert landscape that recreates the sandy dunes of Rajasthan. The player has just collected the Galena, an ore of silver

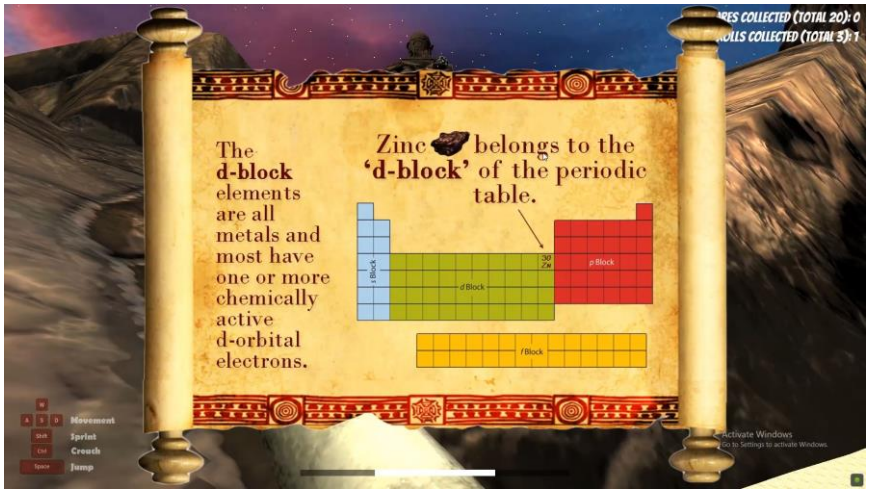

Figure 2: Contents of an unraveled scroll depicting information about the classification of Zinc in the periodic table

Figure 3: Power-up popup in the third level informs players of their newly acquired capabilities

DELIMITATIONS OF THE STUDY

A significant delimitation of this study was that the game development and research were in the English language, and the medium of instruction within the game was also English. The choice to adopt this language as the common medium was twofold. First, English was the only language that could be common as a learning subject in all the classrooms and no regional language like Hindi, Telugu, Gujarati, etc., would have been common for the entire demographic. Secondly, the overarching research was also interested in gauging the potential of using games to teach new words and vocabulary, therefore the adoption of a common, but second language was considered appropriate. The language of the controlled experiments was also English for this same reason. However, in consideration of the future of this research, it can be inferred that the understanding of game-based learning environments in a country like India would be largely benefited if the medium of instruction and evaluation was also translated into the regional languages. There is no doubt that there can be more findings that can come out of students learning and then performing on tests and expressing their views during focus group discussions in the language that they feel more comfortable with.

Lastly, even though the entireties of the experiments have been conducted with the presence of an independent observer, the author still acknowledges the potential of researcher's bias that can manifest itself when a researcher tries to evaluate and test their own creations.

CONTROL-EXPERIMENT STUDIES

This section describes the control-experiment studies of two schools, namely, *St Mary's Higher Secondary School* and *Colonel's Academy*. All three studies comprised research where only the experimental group underwent the game-based intervention, while the control group refrained from it. The following hypotheses were formulated and tested for:

Null hypothesis (H0): There is no significant difference between the performance changes of the experimental group versus the control group

Alternative hypothesis (H1): There is a significant difference between the performance changes of the experimental group versus the control group.

Experiment 1

The first experimental study took place in the form of a randomized control group pretest-intervention-posttest methodology at St. Mary's school for 44 participants. The participant pool was segregated into two groups of 22 each. Only the experiment group underwent the game-based intervention.

Sample

The sample group for this study was the 11th standard class at the school. This institution is a girls' school. Therefore the sample group is solely comprised of girl participants. This section of the class was comprised of students who had opted for STEM subjects as their specialization post-10th standard. Here, as the students were in the final stages of their 11th standard, it was pre-supposed that they would have had a chance to learn the content of the chapter *Classification of Elements and Periodicity in Properties* through the traditional practices of teaching and learning in school.

Pretest-Intervention-Posttest

The entire population of the class comprised 44 students who were segregated into 22 participants for the control group and 22 for the experiment group. The entire class was given the pretest questionnaire collectively, and they were allowed approximately 20 minutes to complete the test, after which the bifurcation of the control group and the experimental group took place.

The control group was placed in another classroom for the duration of the intervention, which was two consecutive periods of 45 minutes, totaling 90 minutes. The experiment group, on the other hand, was invited into the IT labs of their school, where the game-based application had been installed on 22 respective computers. The participants were given a brief introductory play through of the game and were informed about the key bindings within it. After this, the participants were asked to play the game and were urged to complete it, if possible. The students were allowed to make notes during gameplay and were helped by the researcher whenever needed. It was left to the students to proceed with the game, and the gameplay was not guided by the researcher. During this intervention, the control group proceeded with their regular classes as usual.

Once the duration of the intervention was over, the control group and the experiment groups were once again seated together, and the same questionnaire from the pretest was applied again. The testing conditions were kept as similar as possible to the pretest. After the posttest, the control group was also allowed to play the game informally.

Analysis

The responses from both groups were recorded and summed to produce an overall pretest and post-test score, which enabled the researcher to gauge any changes in the performances of the participants. When the participants of the control group were evaluated individually, it was observed that out of the 22 participants: 10 students showed a positive change in their performances, 8 showed no change, and 4 participants showed a negative change in their performances between the pretest and the posttest

The average performance of the pretest for the control group was 7.2 points (out of 14), the average performance of the post-test for the control group was 6.7 points, and the average change in performance for the individual participants was 0.47 points, which translated to a 3.36% change.

When the participants of the experimental group were evaluated individually, it was observed that out of the 22: 21 participants showed a positive change in their performances, 0 participants showed no change, and 1 participant showed a negative change in their performances between the pretest and the posttest

The average performance of the pretest for the experimental group was 7.11 points (out of 14), the average performance of the post-test for the control group was 11.31 points, and the average change in performance for the individual participants was 4.22 points, which translated to a 30.19% change. Table 1 describes the statistical details of the pretest and post-test performances of both the control and experimental group for the first experimental condition.

Mann Whitney U Test

Upon calculation, the distribution was found to be approximately normal. Therefore, the Z-score is used. The U-value for this sample is 33, and the Z-score is -4.89404. The p-value was found to be $< .00001$, and therefore the result can be considered significant at $p < .01$. This indicates that for this particular group, there was a statistically significant difference in the performance change in the post-test of the experimental group when compared with the control group and this change can be positively attributed to being caused by the game-based intervention.

Experiment 2

The second experimental study took place in the form of a randomized control group pretest-intervention-posttest methodology at the Colonel's Academy school for 30 participants. The participant pool was segregated into two groups, with 14 participants in the control group and 16 participants in the experimental group. Only the experimental group underwent the game-based intervention.

Sample

The students of this study belonged to the 8th standard and were comprised of boys as well as girls. The population of 20 students was bifurcated into two groups (see figure 4).

Figure 4: Class 8th students of *Colonel's Academy* playing *Tattva Bhoomi*

Pretest-Intervention-Posttest

The pretest took place collectively for the entire class, after which the control group proceeded with their regular classes, and the experimental group was able to access the gaming intervention. The pretest was approximately 20 minutes.

The intervention duration for this group was a single period of 60 minutes, and the entire study was completed within a single day. Same as before, the participants were given a brief introductory play through of the game and were informed about the key bindings within it. After this, the participants were asked to play the game and were urged to complete it, if possible. The students were allowed to make notes during gameplay and were helped by the researcher whenever needed. As with the previous study, it was left to the students to proceed with the game, and the gameplay was not guided by the researcher. During this intervention, the control group proceeded with their regular classes as usual. All the participants of the experimental group were able to complete the game in the given time frame.

The post-test protocol was the same as before, where the control and experimental groups were sat together and asked to complete the same questionnaire as the pretest. The testing conditions were aimed to be kept consistent throughout the pretest as well as the post-test. The control group was allowed to interact with the GBL application after the post-test.

Analysis

For the control group of the 8th class, it was noted that out of the 14 students: 4 students showed a positive change in performance, 2 students showed a negative change, and 8 students depicted no change in their performance.

The average performance of the control group was 2.25 points for the pretest and 2.57 for the post-test (out of 14 points). The average change in performance for the individual participant was 0.46 points, which translates to a 3.31% change.

When the experimental group was evaluated individually, it was noted that out of the 16 participants: 15 showed a positive change in performance between their pretest and the post-test, 1 participant showed no change, and 0 participants showed a negative change in their performance.

The average scoring for the pretest for the experimental group was 0.5 points, and the post-test average had increased to 7 points (out of 14). This translated to a 46.42% change in performance. Table 2 depicts the change in performance for both groups respectively.

Mann Whitney U Test

Upon calculation, the distribution was not found to be approximately normal. Therefore, the critical value for U based on the alpha level was calculated, and it was found that the U-value was 13, which was less than the critical value of U at 50. The p-value was found to be $< .00001$, and therefore the result can be considered significant at $p < .01$. This indicates that for this particular group, there was a statistically significant difference in the performance change in the post-test of the experimental group when compared with the control group and this change can be positively attributed to the game-based intervention.

Experiment 3

The final experimental study took place in the form of a randomized control group pretest-intervention-posttest methodology at the Colonel's Academy school for 68 participants. The participant pool was segregated into two groups, with 35

participants in the control group and 33 participants in the experimental group. Only the experimental group underwent the game-based intervention.

Sample

The students of this study belonged to the 10th standard and were comprised of boys as well as girls. The population of 68 students was bifurcated into two groups.

Pretest-Intervention-Posttest

The execution of the pretest, intervention, and posttest for this sample was the same as the experimental studies described above. The key difference here was the intervention duration for this experimental group was three consecutive periods of 40 minutes each, adding up to a total duration of 120 minutes, and the entire experiment was conducted within a day.

Analysis

In the control group of the 10th class, evaluation of the individuals showed that out of the 35 participants: 15 participants showed a positive change in their performance between the pretest and post-test, 12 students showed a negative change, and 8 participants showed no change in their comparative performances.

The pretest average for the control group was 4.04 points, and the post-test average came out to be 4.28 points (out of 14). The average change in the individual's performance was 0.24 points, which translates to a 1.65% change.

For the experimental group, individual evaluations showed that out of the 33 participants all 33 participants had performed better on their post-tests than on their pretests.

Mann Whitney U Test

Upon calculation, the distribution was found to be approximately normal. Therefore, the Z-score is used. The U-value for this sample is 15.5, and the Z-score is -6.89009. The p-value was found to be $< .00001$, and therefore the result can be considered significant at $p < .01$. This indicates that for this particular group, there was a statistically significant difference in the performance change in the post-test of the experimental group when compared with the control group and this change can be positively attributed to the game-based intervention.

After analyzing the three experiments individually, it can positively be inferred that all of the pretest-posttests revealed a significant difference between the performance of the control groups and the experimental groups. It was observed that the experimental group which underwent the game-based intervention performed better than the control groups on posttests. The null hypothesis (H0) is therefore rejected while the alternative hypothesis (H1) is accepted for all three experiments. It was also noted that the intervention style in which the GBL application was implemented for a single period of 60 minutes, yielded the best results when compared to the other two intervention styles. The statistical results of all three experiments are presented below.

	Control Group	Experimental Group
St. Mary's School	Class 11th	Class 11th
Size	22	22
Intervention Time	2 x 45 minutes	2 x 45 minutes
Pre-test Average	7.2	7.11
Post-test Average	6.7	11.31
Avg. change in points	0.47	4.22
Avg. change in percentage	3.36%	30.19%
Students with positive change	10	21
Students with negative change	4	1
Students with no change	8	0

Table 1: Pretest and post-test change in performance of the control group (left) and the experiment group (right) from St Mary's School.

	Control Group	Experimental Group
Colonel's Academy	Class 8th	Class 8th
Size	14	16
Intervention Time	1 x 60 minutes	1 x 60 minutes
Pre-test Average	2.23	0.5
Post-test Average	2.57	7
Avg. change in points	0.46	6.5
Avg. change in percentage	3.31 %	46.42 %
Students with positive change	4	15
Students with negative change	2	0
Students with no change	8	1

Table 2: Pretest and post-test change in performance of control group (left) and experimental group (right) from Colonel's Academy Class 8th

	Control Group	Experimental Group
Colonel's Academy	Class 10th	Class 10th
Size	35	33
Intervention Time	3 x 40 minutes	3 x 40 minutes
Pre-test Average	4.04	3.69
Post-test Average	4.28	9.3
Avg. change in points	0.24	5.6
Avg. change in percentage	1.65 %	40.01 %
Students with positive change	15	33
Students with negative change	12	0
Students with no change	8	0

Table 3: Pretest and post-test change in performance of control group (left) and experimental group (right) from Colonel's Academy Class 10th

DISCUSSIONS AND CONCLUSION

In a world where educational games show the potential to uplift the quality of learning, the pedagogy should also evolve to support the changing landscape of education. This study positions itself to reveal insights into an improved understanding of the potential of game-based learning, specifically in the Indian education system, but also for education in general. It provides empirical research that acts as evidence for endorsing a pedagogical rationale for the employment of game-based applications in certain classroom settings and presents a comparative evaluation of the effects of different intervention implementations.

The quantitative results reveal significant changes in the performance of participants where it is found that the participants who experienced Tattva Bhoomi, a first-person exploration-based game fared better in the administered post-test when compared to the participants who did not experience it. The improvement in the performance of the experimental groups was found to be consistent in all three experiments. However, it was also observed, that the intervention style, in which the game-based experience was administered for a single period of 60 minutes, yielded the best results among all three experiments. This data is pertinent for furthering the understanding of the integration of games and educational pedagogy. Researchers can use this data as a guiding measure to further test game-based learning. Tattva Bhoomi is only limited to imparting knowledge of the chemistry subject, however, the findings of this study indicate that other game-based applications, if designed well, could also be able to impart knowledge from other class subjects as well. However, that is the scope of future studies.

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ENDNOTES

1 Video gameplay of *Tattva Bhoomi:*
https://www.youtube.com/watch?v=Khp2X39pEbA