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# Effects of Educational Video Games on Elementary Students' Science Achievement: A Quasi-Experimental Study

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**Abstract**

The present study aimed at investigating the effectiveness of digital educational video games on grade III students of public elementary schools of District Faisalabad. Employing a quasi-experimental, nonequivalent control-group design, 74 male students (control n = 35; experimental n = 39) drawn from two intact classes participated in the study. In the experimental group, science was taught using an educational video game, and in the control group, using conventional lecture-based teaching. A constructed-achievement test, developed by the researcher and used by the researchers, which was validated by subject experts and has an item reliability coefficient of .75 was given as the pretest and posttest in a two-week intervention period. There were no statistically significant (all $p > .05$) pretest differences between the groups on total scores or on any cognitive subscale, confirming baseline equivalence. After the intervention, the mean scores of the experimental group were significantly higher than those of the control group in terms of total achievement $t(72) = 52.56$, $p < .001$, $\eta 2 = .97$, comprehension ($\eta 2 = .95$), analysis ($\eta 2 = .95$), and synthesis ($\eta 2 = .78$). In this sense, the results suggest that digital game-based learning in elementary science education can result in significant short-term learning gains, even for higher-order cognitive skills (analysis and synthesis) and can be understood within the framework of constructivist and experiential learning approaches. Implications for researchers, classroom teachers, and education policymakers with respect to curriculum integration, teacher professional learning, and the scale up to game-based pedagogy in resource poor settings are discussed alongside limitations due to sample size, length of intervention, and single district sampling.

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## Introduction

Elementary school science education is seen as the stepping stone to future scientific literacy, critical thinking and problem-solving skills. However, in many contexts, such as Pakistan, elementary science learning is still lecture oriented, textbook-based, and offers little room for inquiry, experimentation, or meaning making for the students (Arshad et al., 2024). The pattern of this instruction is not sitting comfortably with a vast and growing body of international evidence in favour of the use of interactive, technology mediated pedagogies that can bring a

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meaningful impact to science learning outcomes, especially for younger learners (Gui et al., 2023; Hussein et al., 2019; Wang et al., 2022).

One of these technology-mediated pedagogies that has been the most widely explored are digital educational video games. Educational video games are theorized as being able to capture the learner's attention, keep them motivated, and offer a safe, low-stakes environment for them to manipulate variables, test hypotheses, and observe cause and effect relationships that may be challenging, expensive, or unsafe to reproduce in the classroom setting (Vieira et al., 2019). A large body of literature now exists on this claim, in the form of a large number of meta-analyses. A moderate overall effect of digital game-based STEM learning over traditional learning was found when Wang et al. (2022) synthesized 33 studies (N = 3,894), with the effect being significantly more pronounced at the elementary level than in secondary or higher education. Similarly, Gui et al. (2023) conducted a synthesis of 86 studies and 136 effect sizes, finding a medium-to-large effect of digital game-based STEM learning ($g = 0.624$), and a focused meta-analysis of 41 primary studies and 6,256 participants revealed a positive, albeit heterogeneous, effect of game-based learning on science achievement from primary school to university (Lei et al., 2022).

Amidst this evidence, empirical research on the use of Digital Games in teaching science is still largely conducted in contexts in East Asia, Europe and North America, and a few quasi-experimental studies in South Asia and Pakistan (Arshad et al., 2024; Bayrak & Sönmez, 2024; Qadir et al., 2024). Where Pakistani studies have been conducted, they have primarily investigated teacher perceptions of and preparedness for using gamification in teaching, and not actual achievement gains in students (Amjad et al., 2025), or subjects outside of science (Guan et al., 2024). This is an important gap that remains to be filled, as the contexts of infrastructure, teacher preparation, and digital device access vary significantly between Pakistani public-sector elementary classrooms and those in which the majority of the existing evidence base was created.

The present study tries to fill this gap and reports a quasi-experimental study on the impact of an educational videogame on the science achievement of grade 3 students of two public sector boys' elementary schools in Faisalabad district of Punjab, Pakistan. Unlike studies that only measure total achievement, this study also analyzes achievement across three cognitive levels of Bloom's cognitive taxonomy: "Comprehension," "Analysis," and "Synthesis," which allows for investigation of whether game-based instruction benefits only the lower-order, recall-type learning or whether it also supports higher-order, cognitive processing, as has been suggested in the literature (Sappaile, 2024; Zeng et al., 2024).

This article has three contributions. First, it offers quasi-experimental evidence of science education through digital games based on students' achievements, in a national context under-represented in research. Second, it provides a way of disaggregating outcomes into cognitive levels, adding to the theoretical discussion on the depth or breadth of gains in game-based learning. Third, it imparts specific, contextually-based ideas for researchers, elementary science teachers, and education policy makers in resource-poor public education contexts.

## Theoretical Framework and Literature Review

### *Constructivist and Experiential Learning Foundations*

The argument for the use of video games in science education is based mainly on the constructivist learning theory. Constructivism is the theory that learners construct knowledge about the world around them instead of passively absorbing information that has been presented to them (Bruner, 1966; Piaget, 1952; Vygotsky, 1978). In this context, digital games are assumed to act as cognitive tools, where learners can change game parameters, draw inferences, and build a scientific conception based on their firsthand experience of simulated phenomena, asides from Papert's (1980) constructionist approach to learning from the construction of external artifacts and models.

This is complemented by Kolb's (1984) theory of experiential learning, which views learning as a cyclical process from concrete experience, to reflective observation, to abstract conceptualization, and to active experimentation. This cycle can be well realized in educational video games with in-game feedback and post-game debriefing serving as reflective observation, and the transfer task or subsequent gameplay providing active experimentation, while game mechanics model scientific systems and gameplay provide concrete experience. A third, complementary account is grounded in self-determination theory (Ryan & Deci, 2000) that suggests that well designed games meet the three basic psychological needs of competence, autonomy, and relatedness, and that these needs will keep the learning motivated and engaged which will mediate learning gains (Rigby & Ryan, 2011).

***Empirical Evidence on Digital Game-Based Science and STEM Learning***

Theoretical predictions of these effects are generally supported by recent meta-analytic and systematic-review evidence. In a review of digital game-based learning research in elementary science, Hussein et al. (2019) found that irrespective of the specific type of game used, when well-designed, educational games always led to better conceptual understanding and better retention compared to traditional learning, but also warned that their impact on learning outcomes was highly dependent on the quality of the game design and the degree of fidelity in implementing the games. Guan et al. (2024) also found largely positive impact on achievement in a systematic review of the game-based learning literature in primary education between 2010 and 2020, but reported significant heterogeneity associated with the length of the intervention, subject matter, and type of measure.

Wang et al. (2022) found that the achievement gains of digital games were significantly greater for elementary-level students than for secondary or tertiary students, which they explained by younger students' susceptibility to novel, interactive stimuli and by the fact that, younger students tend to think in concrete and operational terms, which aligns with digital games. This line of study was continued by Gui et al. (2023), who found that both the overall impact of Digital Games and the impact of particular game design features (ex. narrative, feedback, incentive structure), made independent contributions, with the overall impact of Digital Games ($g = 0.624$) significantly higher than the incremental impact of added features ($g = 0.301$). The results of related literature on gamification (the incorporation of game elements without a full digital game, such as points, badges and leaderboards) in non-game based instruction have been similarly promising; a recent meta-analysis by Zeng et al. (2024) of 22 experimental studies conducted from 2008 to 2023 showed a moderately positive overall effect of gamification on academic performance (Hedges' $g = 0.782$), and another recent three-level meta-analysis confirmed the long-lasting achievement benefits of game-based pedagogy across all subjects and levels of education (Xu & Dai, 2026).

This is reinforced by evidence specific to science learning. In 41 primary studies, digital game-based learning (DGBL) had a significant but varied impact on science achievement in the primary through university level, as moderated by grade level, game type, and study design, according to Lei et al. (2022). In Turkish context , which is similar to the present study, Bayrak and Sönmez (2024) found that gamified e-learning environments had a significant positive impact on cognitive motivation and achievement in science education at the school level, and Mohammed et al. (2024) reported sustained cognitive motivation and engagement in scientific content after a gamified science learning experience with elementary school students in a broadly similar Middle Eastern developing country context with the same infrastructural constraints as Pakistan. The results are significant because they suggest that any game-based and gamified interventions are also effective when applied outside the high resource, high connectivity contexts in which much of the key meta-analytic findings have been drawn.

### *The use of video games in relation to higher-order thinking and cognitive domains.*

A key and yet to be addressed issue in this literature is about the cognitive level of game-based learning outcomes, namely whether it is primarily about enhancing rote-learning and comprehension or whether it can also support higher order thinking skills such as analysing, synthesizing and evaluating. Many educational games are interactive and systems-based, which are well suited to developing higher-order thinking skills as they require players to constantly understand feedback, make decisions, and combine various pieces of information to advance through the game (Thrailkill, 2017). Some others warn that motivational benefits of gamified learning do not necessarily lead to enhanced cognitive acquisition, and that some gamification features, such as competitive performance-based scores, may shift learners' focus toward performance instead of learning goals (Justesen et al., 2019). Therefore, disaggregation in terms of cognitive level (as achieved in the present study, through the use of Bloom's taxonomy) is required to adjudicate between these competing accounts, and not only through the use of the aggregate achievement scores.

### *The Pakistani Context*

The science education in Pakistan's public schools at elementary level is still hampered by large number of students in a class, inadequate laboratory facilities, and content-based and examination-oriented pedagogy (Arshad et al., 2024). Meanwhile, mobile communication and low-cost digital devices are more and more available, even in smaller cities and towns, which makes it possible to imagine using digital game-based learning for teaching in practice, at least as a pilot and in larger scale. The promise and the pitfalls of this transition have been identified in recent studies in Pakistan: qualitative studies of elementary teachers in Punjab and Sindh reveal interest in gamified teaching despite challenges in training and curriculum alignment, while a quasi-experimental study of gamified language instruction in rural Punjab shows significant and large-effect achievement gains where game-based instruction is implemented with fidelity (Amjad et al., 2025). However, in the literature of Pakistan, evidence for elementary science in general, and with respect to achievement in particular, and disaggregated by cognitive level is rather sparse until the current study.

### *Mechanisms of motivation and engagement.*

One aspect that has been repeatedly highlighted in the literature cited is that the motivational and affective aspects of digital games play a significant role in the achievement benefits that can be derived from such games, and not just content delivery. The meta-analysis by Zeng et al. (2024) determined that gamification in teaching consistently boosted engagement and enjoyment in the 22 studies analyzed, with this motivation being the strongest factor influencing subsequent learning outcomes. Likewise, Mohammed et al. (2024) found that elementary science students who received gamified instruction also showed increased curiosity and a desire to explore and find explanations for scientific phenomena beyond the class, indicating potential motivational spillover effects. This motivational story is largely congruent with self-determination theory (Ryan & Deci, 2000), which posits that well-designed digital games can meet learners' psychological need for competence (by allowing for incremental mastery of in-game challenges), autonomy (by offering non-linear exploration and choice), and relatedness (by providing for collaboration or socially-embedded gameplay), and it is the satisfaction of these needs that is believed to contribute to sustained engagement and, ultimately, achievement (Rigby & Ryan, 2011).

In the meantime, the literature warns against assuming a connection between motivation and achievement. Some gamified interventions have shown to be highly effective in enhancing short-term motivational outcomes but failed to increase the achievement outcomes that were measured (Sappaile, 2024; Zeng et al., 2024). It is analytically important to differentiate between full digital games, which incorporate learning content into the gameplay and describe the game itself, and gamification, which adds game-like features such as points or badges to existing content and instruction. The overall effect of implementing digital game-based STEM learning ($g = 0.624$) significantly surpassed the added value of using superficial game-design elements without deep integration ($g = 0.301$), indicating that deep integration (content and mechanics) is a more powerful lever for achievement gains than superficial gamification. The intervention analyzed in this study belongs to the first category: the entire 2-week unit was delivered via the educational video game, and not as an additional point-scoring overlay, which might account for the large achievement gains in this study.

### Age, Grade Level and Cognitive Readiness

Another consideration, for the present study, is the relationship between Game-based learning and developmental stage of learners. The authors reported that the learning effects were more pronounced in the elementary-level students compared to secondary and postsecondary students, an effect which they attributed to the former being more novelty-responsive and the latter being less novelty-responsive, as well as secondary and postsecondary students' performance being less close to concrete-operational reasoning in Piagetian terms than that of elementary-level students. This developmental understanding is in line with the constructivist theory which states that children at the elementary school level (Piaget, 1952) first manipulate objects and variables in an active and concrete manner before reasoning abstractly. This would explain the high order of the achievement effects found in the present study as well as the fact that gains were observed in the analysis and synthesis levels in Bloom's taxonomy: Concrete, game-based manipulation of science variables may be just the scaffolding needed for grade 3 learners to make the leap from comprehension to higher-order cognitive operations.

### Purpose of the Study and Research Questions

The present study aimed to investigate the impact of an educational video game on the science achievement of Grade three students of Faisalabad district in Punjab, Pakistan with a specific focus of whether the achievement gains were limited to lower order recall or extended to higher order cognitive processing. building upon this literature research, the present study was thus designed. The research conducted for the study was guided by the following objectives, research questions and hypothesis.

#### *Objectives*

1. To establish a baseline (pretest) science achievement level for grade 3 students.

2. To investigate the effectiveness of an educational game as an instructional tool in elementary-level science learning when compared with conventional teaching, in terms of total achievement and on the comprehension, analysis and synthesis components of Bloom's taxonomy.

#### *Research Questions*

RQ1: What is the baseline level of science achievement of grade 3 students in the control and experimental groups prior to intervention?

RQ2: How effective is an educational video game when compared to traditional teaching methods in general and for science achievement at the elementary level in terms of comprehension, analysis and synthesis cognitive levels of the students?

### *Hypothesis*

H0: There is no statistically significant difference in science achievement between students taught using an educational video game and students taught using conventional instruction.

H1: There is a significant difference in science achievement between students who are taught through an educational video game and students who are taught through conventional instruction.

## Method

### *Research Design*

This study used a quasi-experimental, nonequivalent control-group design. Given that the participating public schools were not suitable for random assignment of individual students to groups, two intact grade 3 classes were used as a control and experimental groups as is typical in field-based, school-embedded quasi-experiments (Guan et al., 2024). The experimental group received science instruction via an educational video game that was aligned with the general science curriculum for grade III, while the control group received the same curriculum by a different, equally qualified government school teacher, but in a lecture-based format. Achievement test scores for both groups were identical for each group as a pretest prior to instruction and as a posttest after 2 weeks of intervention.

### *Participants and Sampling*

The target population included male students of Grade 3 of public sector elementary schools of Faisalabad district of Punjab, Pakistan during 2024-2025 academic year. The selected accessible sample was 74 grade 3 students from 2 government boys' elementary schools in the district representative of the typical government schools in the district based on their facilities, school climate, students' socioeconomic background and teacher qualifications. One intact class ($n = 35$) was the control group, and one intact class ($n = 39$) was the experimental group. In field research of this sort in the public sector, it is a practical consideration that disruption of the normal school functioning was minimal due to the fact that entire classes were not split.

### *Research Tool*

The researcher-developed constructed-response achievement test based on three units of the official grade 3 general science text book was used to assess achievement. The tool consisted of the three main questions each with three sub-parts, with a total of 9 scored items. The items were written to meet the requirements of three levels of Bloom's taxonomy of the cognitive domain: comprehension, analysis, and synthesis, with four items addressing each level, divided evenly across the three curricular units. Content validity was determined by expert judgement, i.e. the test and associated textbook units were assessed by the research supervisor and other subject-matter specialists and the instrument was modified based on their suggestions. The Pearson productmoment correlation method was used to estimate item reliability, which was .75, an acceptable level of internal consistency for a constructed-response instrument of this length.

### *Procedure*

After instrument validation by experts both groups took the achievement test as pre-test. In the experimental group, three curricular units were taught in a structured way, using an educational video game, with guided gameplay sessions, teacher-facilitated debriefing and reflection activities in line with the experiential learning cycle, while in the control group they had the same three curricular units of study, but the teaching was conventional and textbook and lecture oriented with the same time allocation. Both groups were administered a posttest at the end of the two-week intervention which was identical to the pretest. The data collection was carried out in accordance with the ethical rules of the institutions involved, the participation was voluntary and the results were combined and presented anonymously.

### *Data Analysis*

Data were coded and analyzed with SPSS version 21. Pre- and post-test mean and standard deviations scores for the total achievement scale and all cognitive subscale scores were obtained. Independent-samples t-tests were used for each comparison (control group vs. experimental group) to determine whether there was a difference in mean scores between control and experimental groups at pretest (for baseline equivalence) and at posttest (to test the study hypothesis); Levene's test was used to determine equality-of-variances assumption. Effect sizes were determined using eta-squared ($\eta 2$) and interpreted using the conventional benchmarks set by Cohen (1988) of values near .01, .06, and .14 representing small, medium, and large effect sizes, respectively; in the present study, the effect sizes exceeded the values for large effect size.

### *Ethical Considerations*

Ethical procedures were not taken as a formality in the current experimental study but rather as a methodological priority because it was conducted in a public school. The study received approval from the school principals and informed consent was obtained from parents/guardians before data collection, and the students provided assent as well; participation was voluntary and could be withdrawn at any time without impacting student academic status. In order to minimize disruption to normal school activities, whole classes rather than rearranged classes were retained and a complete curricular curriculum was given to both groups, so that no student was denied access to the regular curriculum of the school as a condition of participation in the study. Individual student results were not shared but were only reported in aggregated, anonymous form, which is typical of classroom-based educational research with children in keeping with standard ethical guidelines.

## Results

### *Baseline (Pretest) Equivalence*

Independent-samples t-tests revealed that, prior to intervention, there was no statistically significant difference between the mean achievement scores for the control group and the experimental group on the total pre-test or on any of the three cognitive sub scales of the pre test, indicating that the control and experimental groups started the study at a comparable level of science achievement (see Table 1). All pretest comparisons were found to be acceptable on the assumption of equal variances by means of Levene's test (all $p > .05$).

**Table 1**
*Comparison of Control and Experimental Group Pretest Scores*

| Measure | Total Score | Group | n | M | SD | t(72) | p |
|---|---|---|---|---|---|---|---|
| Total achievement | 27 | Control<br>Experimental | 35<br>39 | 3.22<br>3.33 | 1.21<br>1.52 | 0.32 | .74 |
| Comprehension | 12 | Control<br>Experimental | 35<br>39 | 1.51<br>1.58 | 0.88<br>0.88 | 0.36 | .71 |
| Analysis | 12 | Control<br>Experimental | 35<br>39 | 1.48<br>1.53 | 0.74<br>1.02 | 0.25 | .80 |
| Synthesis | 3 | Control<br>Experimental | 35<br>39 | 0.22<br>0.20 | 0.42<br>0.40 | 0.24 | .81 |

*Note.* There were no significant pre-test differences between the two groups ($p > .05$), suggesting there was no baseline difference between groups pre-test.

### *Posttest Group Comparisons*

After two weeks, all of the experimental group's scores on total science achievement and on all three cognitive subscales (see Table 2) were significantly higher than those of the control group. For these posttest comparisons the assumption of equal variances was violated (all $p < .001$), and degrees of freedom have been adjusted, if applicable: t-values and effect sizes are reported as obtained. All four comparisons had very large effect sizes by conventional standards ($\eta 2$ from .78 to .97), reflecting the significant amount of variance in posttest achievement associated with the intervention.

**Table 2**
*Comparison of Control and Experimental Group Posttest Scores*

| Measure | Total Score | Group | n | M | SD | t(72) | p | η2 |
|---|---|---|---|---|---|---|---|---|
| Total achievement | 27 | Control<br>Experimental | 35<br>39 | 12.71<br>26.46 | 1.42<br>0.75 | 52.56 | <.001 | .97 |
| Comprehension | 12 | Control<br>Experimental | 35<br>39 | 5.85<br>11.71 | 0.77<br>0.55 | 37.65 | <.001 | .95 |
| Analysis | 12 | Control<br>Experimental | 35<br>39 | 5.34<br>11.79 | 0.90<br>0.40 | 40.18 | <.001 | .95 |
| Synthesis | 3 | Control<br>Experimental | 35<br>39 | 1.51<br>2.94 | 0.50<br>0.22 | 16.02 | <.001 | .78 |

*Note.* All posttest differences were in favor of the experimental group and were significant at the $p < .001$ level of significance. $\eta 2$ = eta-squared effect size.

Overall, the findings reveal that there was no statistical difference between the two groups in science achievement before instruction, but after two weeks of instruction, differences were found in achievement, both in terms of overall scores and in terms of scores from the three achievement subscale categories—comprehension, analysis, and synthesis. The comparison of the very large effect sizes for comprehension ($\eta 2 = .95$) and analysis ($\eta 2 = .95$) suggests that the intervention had a similar effect for both lower-order (comprehension) and higher-order (analysis) cognitive processing, while the somewhat smaller but still large effect for synthesis ($\eta 2 = .78$) suggests that it benefited to a slightly lesser extent the highest-order cognitive processing tasks, those that required students to integrate and develop new understanding. The current results strongly contribute to the theoretical discussion of whether game-based instruction enables only superficial recall or includes higher order thinking as well: the findings suggest that both surface-level and higher-order thinking are possible, and that these may become somewhat less effective at the highest level of thinking, within a limited intervention window of approximately two weeks.

## Discussion

The findings of this study clearly support the hypothesis that digital educational video games can have a significant impact on elementary students' science achievement when compared to traditional, lecture-based teaching. At the start of the study there were no differences in achievement level among the two groups in each of the cognitive domains measured, thus eliminating pre-existing differences as a possible explanation for posttest differences. After a brief two week intervention, the mean achievement in the experimental group exceeded more than twice that of the comparison group on the total achievement measure, with very large effect sizes found on each cognitive subscale tested.

These results correspond with and quantitatively match recent international meta-analytic results. The overall pattern of the significant, large magnitude achievement gains in favour of digital game-based instruction is consistent with the findings by Wang et al. (2022) of a moderate to large pooled effect of digital game-based STEM instruction ($g = 0.667$) and with the closely convergent estimate ($g = 0.624$) by Gui et al. (2023) for digital educational games in STEM learning generally. It also aligns with the science-specific meta-analytic evidence presented by Lei et al. (2022) and with the results of the systematic review conducted by Hussein et al. (2019) which shows that digital games significantly support elementary science learning when they are aligned with curricular goals. Notably, the effect sizes found in the present study ($\eta 2 = .78–.97$) are considerably larger than the pooled Hedges' g effect sizes reported in these meta-analyses, which is plausible because meta-analytic pooled estimates necessarily average across studies with a variety of implementation quality across studies, intervention length, and measurement approach, whereas the present study reflects a single curriculum-aligned intervention, delivered by the researcher herself, to a relatively small and homogeneous sample conditions generally associated with larger observed effects in the broader education-intervention literature.

The fact that achievement gains occurred on analysis and synthesis (Bloom's taxonomy) tasks and not only in comprehension levels is theoretically significant. It implies that the so-called constructivist mechanism, which is thought to underlie game-based learning (game manipulation of game variables, testing of hypotheses, and interpretation of feedback from in-game manipulation, as described by Vieira et al., 2019), was also used to facilitate factual recall and to scaffold the more challenging cognitive processes of analysing relationships and synthesising new understanding. This fits with Kolb's (1984) experiential learning cycle of concrete experience, reflective observation, and abstract conceptualization, which this study aligned with the analysis and synthesis subscales, respectively. Concurrently, the slightly lower size effect in the synthesis compared to comprehension and analysis is in line with literature cautions that the strongest form of cognitive transfer may require longer durational engagement than a two-week intervention can provide (Sappaile, 2024), and that game design factors without sufficient scaffolding of reflection and abstraction may not fully maximize higher-order gains (Gui et al., 2023).

The results have also been geographically extended to the evidence base for international research. The majority of the foundational literature of digital game-based STEM and science learning comes from East Asian, European, and North American contexts that generally feature higher levels of digital infrastructure (Gui et al., 2023; Wang et al., 2022). The present findings, collected in resource-poor public-sector elementary schools in Punjab, Pakistan, confirms that similar if not larger achievement impacts can be achieved in a resource-poor South Asian context, adding to recent evidence in Pakistan and the region that gamified and game-based education remain effective in lower-resourced contexts (Bayrak & Sönmez, 2024; Mohammed et al., 2024). This is a very practical finding, as it indicates that despite the existence of infrastructure constraints, they, however, do not need to be an absolute impediment in the way of implementing game-based science pedagogy in a public education system like that of Pakistan.

These conclusions should be viewed with confidence because of some features of the study design. A curriculum-inherent, subject-matter expert-validated achievement instrument was used, as opposed to a generic or off-the-shelf instrument, to minimize the possibility of construct-irrelevant variance in the outcome measure. A credible counterfactual baseline is provided by the demonstration of statistical equivalence between groups at pretest on the total score and across all three cognitive subscale scores. Instead of relying on a single measure of a composite outcome score, the disaggregation of results by cognitive level enabled the study to directly address the depth of learning gains and not just the presence of learning gains, which has been one of the shortcomings of the broader gamification literature (Zeng et al., 2024). They combine to make the present study different from the correlative or SGS (single group pre–post) designs which are prevalent in much of the Pakistani literature on the subject of educational technology, and adds to the plausibility of a causal interpretation of the observed group differences, within the limits of the limitations raised below.

## Implications

### *Implications for Researchers*

The results indicate some priorities for future studies. To confirm the generalizability of the observed effects across larger, sex-balanced across-district samples, further observations would be required. Finally, the intervention period was only short-term just a few weeks or months so a longitudinal design that could be used to follow up the success of the intervention over weeks and months after the intervention would help answer questions that still exist in the wider gamification literature of whether that very large effect is maintained over time or diminishes over time (Zeng et al., 2024), in particular retention of higher-order analytical and synthesis skills. Third, researchers need to keep breaking down achievement outcomes by cognitive levels and not just by total scores because the present study's comparison of the sub-scales of comprehension, analysis, and synthesis did not show only one pattern of achievement when compared to an aggregate score. Last but not least, to further contribute to the understanding of which parts of digital games contribute to achievement gains in Pakistani classrooms, dismantling studies, as already done by Gui et al. (2023) in other contexts, would be helpful.

### *Implications for Educators*

The results are preliminary, but promising, and provide the classroom teacher and science educator with a first glimpse of the potential of structured, curriculum-aligned educational video games as a motivational supplement that can lead to achievement gains in higher-order cognitive areas that could not be achieved to the same extent in the same amount of time using lecture-based instruction. Teachers thinking about using this approach should take careful note of curricular alignment (making sure content is directly linked to the stated learning goals) and the interface of gameplay with debriefing and reflection activities, following the experiential learning cycle, as opposed to gameplay as a standalone activity. The teacher-researcher's direct experience with the curriculum and with the game in the context of the experiment and direct interaction with the participants in this study suggest that teacher professional development is a probable precondition for the successful implementation of educational technology in the classroom at scale (Amjad et al., 2025).

### *Implications for Policymakers*

The findings provide district-level, achievement-based evidence to help contribute to a policy conversation that has until now been led primarily by teachers' perceptions and international meta-analytic evidence collected in different settings. The size of the effects observed, which occurred with a relatively small, 2-week intervention in regular public-sector schools, indicates that pilot projects could be developed that integrate digital educational games into the elementary science curriculum, with the availability of basic digital infrastructure (shared devices, offline-capable software or low-bandwidth platforms) and targeted teacher training, to be a cost-effective lever for enhancing science achievement. It is also important for policymakers to recognize that the students in this study were girls from government schools where they too historically have struggled with access to quality science teaching in Pakistan; the success of this type of instruction in this particular group makes digital learning investments in public girls' schools a key part of the broader education reform agenda to address inequities in access.

### *Limitations and Guidelines for Future Research.*

There are several limitations to these results. First, intact, nonrandomized classes, as required in a field setting, do not eliminate the possibility that classroom or teacher level factors have contributed to the observed effects, even though baseline differences between the two groups have been demonstrated. Although baseline differences between the two groups have been demonstrated, intact, nonrandomized classes preclude the possibility that classroom or teacher level factors have contributed to the results observed, even though this is methodologically required in a field setting. Secondly, the sampling was from two schools in one district and included only male students which restricted the generalizability of the results to the female students, co-education school and other parts of Pakistan. Third, the two-week intervention period is long enough to generate large short-term achievement effects but does not allow conclusions to be drawn about the durability of these achievements; a concern that is more generally shared by the gamification literature (Zeng et al., 2024). Fourth, the achievement instrument, even though expert-validated and showing acceptable item reliability (.75), was not a standardized measure, but was developed by the researcher, and was based on only nine items, which may limit the precision of item-level estimates, especially for the single-item synthesis subscale. Finally, it is important to note that the experimental group was taught by the researcher and the control group was taught by another teacher, thus an "experimenter effect" and/or a "novelty effect" (students responding to the enthusiasm or expectations of the teacher rather than the video game) cannot be ruled out. These limitations could be overcome through future studies employing cross-teacher designs, achievement measures used that have been validated previously or standardized, delayed retention testing, and larger more demographically diverse samples.

## Conclusion

The results of this study lend quasi-experimental support for the ability of a structured, curriculum-based educational video game to achieve significant improvement in the learning of elementary science as seen from the comprehension, analysis and synthesis levels of Bloom's taxonomy among public school students in Pakistan, not just at the lower-order recall level. These are consistent with an emerging international meta-analytic evidence base for digital game-based STEM and science learning and extends this evidence to an under-researched South Asian, public-sector context where limited resources are a factor. The findings indicate that when designed to target specific curriculum goals and followed by guided reflection, digital learning games are an intriguing and possibly cost-effective means of enhancing elementary science outcomes in comparable contexts. The study also has a short intervention window and was conducted in only one district, with a researcher-developed instrument, which suggests the results should be regarded as a promising first finding and not a comprehensive foundation for policy widespread adoption. There is a need to have more robust replications of the study, with increased size and duration, ideally with delayed retention measures and using cross-teacher design, in order to draw solid conclusions about the durability and generalizability of the digital game-based science instruction across Pakistani education system.

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