

Investigating Educational Escape Room Games in Mathematics: Effects on Achievement and Perceptions

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Abstract: The use of game-based learning approaches in formal education has gained increasing attention; however, there remains limited empirical evidence regarding the effectiveness of educational escape room games in improving measurable learning outcomes, particularly within mathematics education. In addition, there is a need for structured design approaches that clearly align such game-based interventions with curriculum objectives and learning outcomes. This study aims to address these gaps by investigating the impact of an educational escape room game on students' academic achievement in mathematics, as well as exploring students' perceptions of this innovative learning experience. The study employs a quasi-experimental research design involving an experimental group and a control group within a 6th-grade mathematics context. Two educational escape room games were systematically designed, developed, and implemented in alignment with specific curriculum learning outcomes, following a documented ADDIE-based design and implementation workflow that incorporated collaborative problem-solving tasks, game mechanics, and time-bound challenges. The intervention was conducted over a four-week period (8 instructional hours), during which the experimental group participated in escape room-based learning activities, while the control group received traditional instruction covering the same mathematical content. Quantitative data were collected through pre- and post-tests to measure students' academic achievement, and the results were analysed to compare group performance, including effect-size estimates. The experimental group demonstrated a statistically significant improvement compared to the control group, with a large effect size. Qualitative data obtained through semi-structured interviews further revealed that students perceived the escape room activities as engaging, motivating, and supportive of deeper conceptual understanding, reporting gains in problem-solving skills, collaboration, and self-perceived retention of mathematical content. This study contributes to the field of game-based learning by providing empirical evidence of the effectiveness of educational escape rooms in mathematics education and by presenting a structured, curriculum-aligned escape room design approach. The findings offer practical implications for educators and instructional designers seeking to integrate interactive, collaborative, and immersive learning environments into formal educational settings, whilst highlighting the need for further research with larger samples and delayed retention measures.

Keywords: Game-based learning, Educational escape room, Mathematics education, Academic achievement, Instructional design, Collaborative learning

1. Introduction

Mathematics is widely regarded as a pivotal discipline in compulsory education, yet student disengagement and anxiety in the subject remain persistent challenges. Traditional, teacher-centred instruction — characterised by rote memorisation of rules and procedures — has been repeatedly associated with low motivation, passive learning, and poor long-term retention (Tural, 2005; Akın and Cancan, 2007). In response, educational researchers have increasingly turned to game-based learning (GBL) as an active, learner-centred alternative capable of transforming the classroom into an engaging, meaningful environment.

Within the broader GBL landscape, escape rooms have emerged as a particularly innovative format. Originating in commercial entertainment (Nicholson, 2015), escape rooms challenge participants to decode puzzles, follow clues, and achieve a shared objective within a fixed time. Their educational adaptation — the educational escape room (EER) — retains these engaging mechanics whilst embedding curriculum content, fostering collaboration, critical thinking, and immediate formative feedback (Moura and Santos, 2019).

Despite growing interest, empirical research on EERs in compulsory school mathematics is sparse. Most published studies are situated in higher education or medical training (Borrego et al., 2016; Jambhekar et al., 2020), leaving a gap regarding the pedagogical effectiveness of EERs with younger learners and in formal curriculum contexts. This study addresses that gap by asking two research questions:

- Is there a statistically significant difference in mathematics achievement between sixth-grade students taught via an educational escape room and those taught through traditional instruction?
- What are the perceptions of experimental group students regarding learning mathematics through an educational escape room?

By combining a quasi-experimental control-group design with a documented, replicable ADDIE-based design framework and transparent effect-size reporting, this study extends prior, predominantly descriptive accounts

of educational escape rooms and offers a more rigorous evidential basis for their use in compulsory mathematics education.

2. Literature Review

2.1 Game-based Learning

Game-based learning encompasses learning environments in which game mechanics — including narrative, challenge, feedback, and reward — drive educational objectives (Ebner and Holzinger, 2007). The evidence base is substantial: GBL has been shown to improve academic achievement, motivation, and collaborative learning across a range of subjects and age groups (Wang and Khambari, 2020). Garriss, Ahlers and Driskell (2002) formalised this relationship through an input-process-output model in which game characteristics trigger repeated engagement cycles, ultimately producing measurable learning outcomes. In mathematics specifically, GBL enables the concretisation of abstract concepts and supports multi-step problem solving in contextualised settings (Güneş, 2010; Song, 2017).

Notwithstanding this generally positive picture, the broader GBL evidence base remains methodologically uneven. Reported effect sizes vary considerably across studies, comparison conditions are inconsistently defined, and many interventions are short in duration, making it difficult to separate the effects of novelty from those attributable to the underlying pedagogical design (Wang and Khambari, 2020). Relatively few studies report standardised effect sizes alongside significance values, which limits comparability across contexts, subjects, and age groups and constrains the development of cumulative, generalisable evidence — a gap that the present study seeks to address through transparent effect-size reporting.

2.2 Educational Escape Rooms

Educational escape rooms adapt the commercial escape room format for pedagogical ends. Participants — typically organised in small teams — must solve a series of interconnected puzzles whose solutions are embedded in curriculum content, with the ultimate goal of ‘escaping’ (unlocking a box, decoding a final cipher, or completing a narrative) within an allotted time. Nicholson (2015) identifies three primary puzzle-path structures: linear (sequential puzzles), open (simultaneous puzzles feeding a single endpoint), and multi-linear (parallel paths of varying difficulty). Each structure affords different opportunities for differentiation and collaborative role allocation.

Moura and Santos (2019) situate EERs at the intersection of GBL and gamification, noting that they incorporate core gamification elements — narrative, autonomy, immediate feedback, and progression — alongside genuinely game-like challenge mechanics. Csikszentmihalyi’s (2012) flow theory provides further theoretical grounding: well-designed EERs offer appropriately calibrated challenges that keep participants in the optimal zone between boredom and anxiety, sustaining concentration and intrinsic motivation.

Empirical studies report consistently positive outcomes. Borrego et al. (2016) found EERs enhanced motivation among undergraduate computer science students. Jambhekar, Pahls and Deloney (2020) demonstrated collaborative learning and critical-thinking benefits in medical radiology training. Li et al. (2018) reported that problem-based EER tasks encouraged deep learning. Macias (2017) applied an EER to English language instruction in secondary school, documenting strong engagement and curriculum coverage. Notably, however, studies in compulsory school mathematics — particularly at the middle-school level — remain limited, motivating the present investigation.

These contributions notwithstanding, the EER literature exhibits recurring methodological limitations that warrant more critical scrutiny. Borrego et al. (2016) and Jambhekar, Pahls and Deloney (2020) employed single-group or pre-post designs without a comparison condition, making it difficult to attribute observed gains specifically to the escape room format rather than to general novelty effects or additional instructional time. Macias (2017) and Li et al. (2018) drew primarily on qualitative or case-study evidence, offering valuable insight into student experience but limited quantitative evidence of achievement gains. Moreover, the majority of empirical work to date is situated in higher education or vocational training with adult learners, leaving the effectiveness of EERs for younger, compulsory-school learners comparatively under-examined. The present study addresses these gaps through a quasi-experimental design incorporating a control group, a psychometrically validated achievement instrument, and the reporting of effect sizes alongside significance testing.

3. Methodology

3.1 Research Design

A quasi-experimental pre-test/post-test control group design was employed. Random assignment to groups was not possible within the institutional setting; however, independent samples t-test analysis of pre-test scores confirmed equivalence between groups at baseline ($t = -1.173$, $p = 0.249$). Both quantitative (achievement test) and qualitative (structured interviews) data were collected, providing methodological triangulation.

3.2 Participants

Participants were 37 sixth-grade students (aged 10–12) from a private school in Pendik, Istanbul, during the first semester of the 2019–2020 academic year. The experimental group comprised 19 students (11 male, 8 female) and the control group 18 students (11 male, 7 female). Groups were formed by school administration prior to the study and were assigned to their respective conditions by school management. The researcher was responsible for the experimental group class; a separate qualified mathematics teacher delivered traditional instruction to the control group.

3.3 Instruments

A 21-item multiple-choice achievement test covering the topics of Sets and Integers was developed collaboratively by the researcher and five subject-matter experts. A pilot administration with 122 seventh-grade students yielded satisfactory psychometric properties: KR-20 internal consistency coefficient = 0.792, mean item difficulty (p) = 0.657, and mean discrimination index = 0.550. Item difficulty values ranged from 0.09 to 0.877, indicating a suitable spread of difficulty. One item with low discrimination ($r = 0.089$) was retained following expert consensus, as the construct it measured was pedagogically essential; its wording was revised for clarity.

For qualitative data, a structured interview protocol comprising 17 questions was developed in consultation with subject-matter and measurement specialists. Interviews were conducted individually with six purposively selected experimental group participants, representing high, moderate, and low achievement levels (two from each band). Transcripts were subjected to content analysis, with codes, categories, and themes developed iteratively in collaboration with a field expert.

3.4 Instructional Design and Procedure

Two educational escape rooms were designed using the ADDIE instructional design model (Analysis, Design, Development, Implementation, Evaluation), informed by Nicholson's (2015) multi-linear puzzle-path structure. The first game addressed the Sets topic; the second addressed Integers. Both adopted a 'lockbox' format: teams received locked boxes, task cards embedded with curriculum problems, and contextual narrative materials. Solutions to mathematical tasks yielded combinations to open successive locks, culminating in a team finale challenge.

The experimental group played the escape games over four weeks (eight class hours, approximately two hours per game). Students worked in small mixed-ability teams, with the researcher acting as game facilitator but not providing direct instructional scaffolding — guidance was encoded within the game materials themselves. The control group received four weeks of traditional instruction on identical learning objectives, delivered by the regular class teacher using the prescribed textbook and interactive whiteboard. Both groups sat the achievement test before and after the intervention.

The overall design and implementation workflow, structured around the five ADDIE phases and incorporating an iterative feedback loop between the two games, is summarised in Figure 1. Feedback collected from students and observations following the first escape room (Sets) directly informed the redesign of the second escape room (Integers), most notably the introduction of a competitive ranking element.

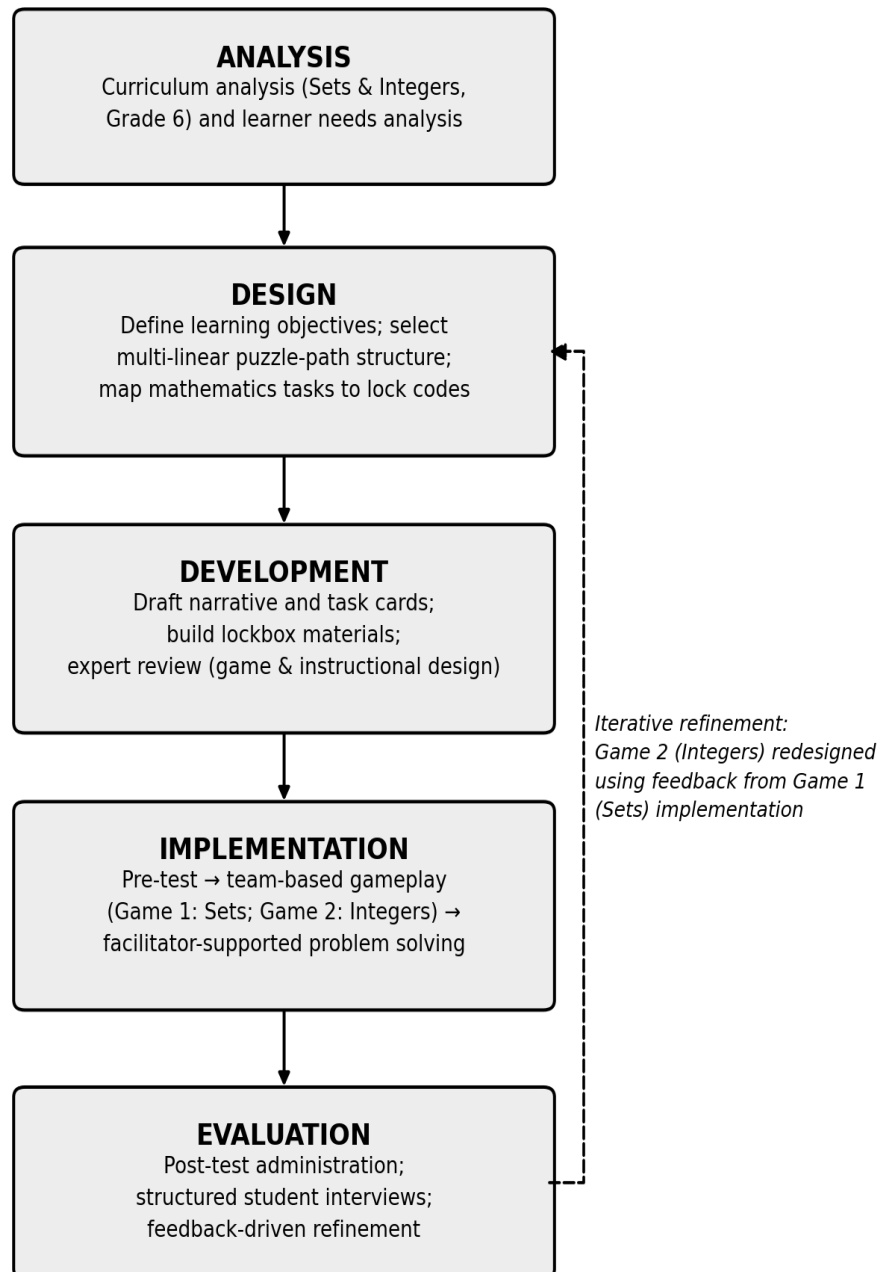


Figure 1: ADDIE-based design and implementation workflow for the educational escape rooms

4. Results

4.1 Pre-test Equivalence

Prior to intervention, no statistically significant difference was observed between experimental ($M = 6.53$, $SD = 4.01$) and control groups ($M = 8.00$, $SD = 3.61$) on the achievement pre-test ($t = -1.173$, $p = 0.249$), confirming baseline equivalence.

4.2 Within-group Pre- to Post-test Gains

Both groups showed significant improvement from pre-test to post-test (Table 1). The experimental group's mean score increased from 6.53 to 17.89 ($t(18) = -12.211$, $p = 0.000$, $dz = 2.80$, 95% CI for the mean gain [9.41, 13.32]), whilst the control group improved from 8.00 to 14.06 ($t(17) = -5.931$, $p = 0.000$, $dz = 1.40$, 95% CI [3.90, 8.21]). Both within-group effect sizes exceed conventional thresholds for a large effect (Cohen, 1988); however, the experimental group's gain was approximately twice that of the control group, both in absolute terms (11.36 versus 6.06 points) and in standardised effect size.

Table 1: Pre-test and Post-test Means by Group, with Effect Sizes*(Paired samples t-test; dz = Cohen's d for paired samples; CI relates to the mean pre-post gain)*

Group	N	Pre-testMean	Post-testMean	t	p	dz	95% CI(mean gain)
Experiment	19	6.53	17.89	-12.21	0.000	2.80	[9.41, 13.32]
Control	18	8.00	14.06	-5.93	0.000	1.40	[3.90, 8.21]

4.3 Between-group Post-test Comparison

An independent samples t-test confirmed a statistically significant difference in post-test achievement between the experimental ($M = 17.89$, $SD = 2.26$) and control groups ($M = 14.06$, $SD = 5.18$), favouring the experimental group ($t(35) = 2.948$, $p = 0.006$) (Table 2). The mean difference of 3.83 points corresponds to a large effect size (Cohen's $d = 0.97$, 95% CI [0.29, 1.65]), with the 95% confidence interval for the raw mean difference spanning [1.20, 6.48]. Although the precision of this estimate is constrained by the modest and unequal group sizes, the magnitude of the advantage associated with the escape room intervention is substantively meaningful and consistent with large effects reported in comparable GBL interventions (Wang and Khambari, 2020).

Table 2: Post-test Comparison Between Groups, with Effect Size*(Independent samples t-test; d = Cohen's d; CI relates to the raw mean difference)*

Group	N	Post-testMean	SD	t	p	d	95% CI(mean diff.)
Experiment	19	17.89	2.26	2.948	0.006	0.97	[1.20, 6.48]
Control	18	14.06	5.18	—	—	—	—

4.4 Qualitative Findings

Content analysis of structured interviews produced five overarching themes: (1) Initial Encounter with the Escape Room, (2) Perceptions of Game Design, (3) Classroom Atmosphere During Play, (4) Understanding of Curriculum Content, and (5) Attitudes Towards Mathematics via Escape Room.

All six participants reported that the escape room format was entirely novel to them; none had previously experienced an EER in any educational context. Upon first encounter, students uniformly expressed excitement and positive anticipation. Representative student voices included: 'I thought it would be fun — and it was' and 'I was so excited; I had seen programmes with codes and locks before.'

Regarding game design, participants praised the integration of locked boxes and hidden task cards as creative and motivating. They expressed a desire for extended duration and greater difficulty, suggesting high intrinsic engagement. With respect to classroom atmosphere, students described a lively, collaborative environment in which peers worked energetically together. Several noted that competitive elements in the second game (medal cards for first, second, and third-place teams) further heightened motivation.

In relation to content understanding, participants reported that escape room mechanics supported their recall of mathematical concepts: 'When I can't remember something about Sets, I think back to the game and how we solved it — and it comes back to me.' Students also indicated that the puzzle-solving process mirrored mathematical problem-solving, reinforcing procedural pathways. Finally, participants advocated for broader adoption: 'Maths is sometimes boring, but like this it's much better. I'd recommend it for all lessons.'

5. Discussion

The findings provide empirical support for the effectiveness of educational escape rooms as an instructional strategy in sixth-grade mathematics. The statistically significant superiority of the experimental group on the post-test ($p = 0.006$, $d = 0.97$) aligns with and extends the existing literature. In higher education, Borrego et al. (2016) and Pernas et al. (2019) reported analogous achievement improvements, and the present study confirms that comparable benefits — of a similarly large magnitude — are achievable in compulsory schooling with younger learners.

The theoretical explanations are multi-faceted. From a flow-theory perspective (Csikszentmihalyi, 2012), the time-constrained, progressively challenging structure of the escape games is well-suited to sustaining optimal engagement. Students' qualitative accounts of losing track of time, intense concentration, and the desire for longer gameplay are consistent with flow experience. From a constructivist standpoint, the requirement to apply mathematical knowledge actively — selecting operational pathways, verifying solutions via lock codes, and revising strategies upon failure — situates learning as a process of knowledge construction rather than passive reception (Tural, 2005).

The collaborative team structure is also noteworthy. Students described peer discussion and division of tasks as natural features of gameplay. This mirrors findings by Wang and Khambari (2020) and Eukel et al. (2020), who identified collaborative learning as a key mechanism through which GBL and EERs enhance outcomes. The lockbox format used in this study — portable, low-cost, and technology-independent — merits particular attention for practitioners with limited resources. Unlike digital EERs or room-scale physical installations, lockbox games require no specialist infrastructure, rendering them feasible for most classroom settings.

5.1 Limitations

Several limitations should be considered when interpreting these findings. First, the sample was drawn from a single private school in Istanbul and comprised only 37 students; this small, context-specific sample limits statistical power and constrains the generalisability of results to other school types, socioeconomic contexts, or national curricula. Second, the experimental and control groups were taught by different teachers. Although both classes followed an identical curriculum sequence and shared learning objectives, monitored through a common planning document, teacher-level differences in pedagogical style, rapport, or enthusiasm cannot be fully ruled out as a confounding variable; future replications should, where possible, hold the teacher constant across conditions or include multiple teachers per condition. Third, the claims regarding improved retention of mathematical content are based on students' self-reports during post-intervention interviews rather than on objective delayed testing; these findings should therefore be interpreted as evidence of perceived, rather than demonstrated, long-term retention, and future studies should incorporate delayed post-tests (for example, administered four to eight weeks after the intervention) to assess whether achievement gains are sustained over time. Finally, although effect sizes have been reported here to aid interpretation, the relatively small and unequal group sizes ($n = 19$ and $n = 18$) produce wide confidence intervals, and these estimates should be corroborated with larger samples drawn from multiple classes and schools.

6. Conclusion

This study demonstrates that a purpose-designed educational escape room can significantly improve sixth-grade students' mathematics achievement relative to traditional instruction, with a large effect size, whilst simultaneously fostering motivation, collaboration, and positive attitudes towards the subject. The multi-linear lockbox format, implemented through the documented ADDIE-based workflow shown in Figure 1, proved pedagogically sound and practically accessible. The convergence of quantitative and qualitative findings strengthens confidence in these conclusions, although the limitations discussed above indicate that they should be treated as preliminary rather than definitive.

For practitioners, the study offers a validated, visually documented design framework — grounded in the ADDIE model and Nicholson's (2015) puzzle-path typology — that can be adapted for other curriculum topics and age groups with relatively modest effort. For researchers, the study highlights the need for larger-scale, multi-school replications that retain a control group, employ consistent teaching staff across conditions, and incorporate delayed post-tests to verify whether the perceived retention benefits reported by students translate into sustained achievement gains. Educational escape rooms represent not merely an engaging novelty, but a principled, evidence-based pedagogical tool with significant potential for transforming mathematics classrooms.

Ethics Declaration: This study was conducted in accordance with the ethical standards of Bahçeşehir University. Parental consent and student assent were obtained prior to data collection. The study did not involve sensitive personal data, physical risk, or deception. All student data were anonymised before analysis. Ethical clearance was granted by the Bahçeşehir University Institute of Educational Sciences in 2019 in accordance with institutional review procedures.

AI Declaration: An AI language tool was used to assist in restructuring and condensing the original master's thesis into the conference paper format, to calculate and verify supplementary effect-size statistics from

reported descriptive values, to generate the workflow diagram in Figure 1 from author-specified content, and to support language editing for fluency and clarity in British English. All intellectual content, research design, data collection, analysis, and interpretation remain the work of the authors. The AI-generated text, statistics, and figure were critically reviewed, verified against source materials, and substantially revised by the authors prior to submission.

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