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The Effectiveness of STEAM-Based Immersive Pop-Up Books in Early Childhood Education for Stimulating Understanding of Disaster Mitigation Concepts

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ABSTRACT

Indonesia and West Java are highly earthquake-prone, rendering early childhood children the most vulnerable group due to abstract concept understanding limitations. Conventional mitigation learning remains theoretical, causing cognitive overload. This study aims to evaluate the effectiveness of an immersive pop-up book based on ECE STEAM to stimulate earthquake mitigation conceptual understanding. A quantitative experimental design was applied to a sample of 17 children aged 4–6 at KB Wisana Cidadap, Bandung. Data were gathered via illustrated test instruments and analyzed using Paired Sample t-Test, N-Gain, and Cohen's d Effect Size. Results showed a significant mean score increase from 72.94 (SD = 14.55) in the pre-test to 87.88 (SD = 8.40) in the post-test. The Paired Sample t-Test yielded a significance of < 0.001 (H_1 accepted),

with an N-Gain score of 0.5280 (medium category) and an Effect Size of 1.571 (very high category). In conclusion, ECE STEAM-based immersive pop-up book media is highly effective in reducing cognitive load and meaningfully improving early childhood disaster mitigation understanding.

Introduction

Indonesia has a very high level of disaster vulnerability, dominated by hydrometeorological disasters such as floods, landslides, and extreme weather events that occur frequently every year. According to the 2024 Indonesia Disaster Data released by the National Disaster Management Agency (BNPB), approximately 99.34% of disasters in Indonesia are hydrometeorological disasters—that is, disasters influenced by weather and surface runoff (BNPB, 2025). In addition, earthquakes are a common type of disaster in Indonesia, accounting for 1.43% of all disasters across the country, according to the 2024 Disaster Data. West Java Province itself is an earthquake-prone region, due to the presence of numerous active faults and a megathrust zone—a thin layer located between a plate subducting into the Earth's mantle and the overriding plate (Zulfa, 2018). According to data released by the National Disaster Management Agency (BNPB) in the 2024 Indonesian Disaster Data, there were a total of 28 earthquake events across 19 regencies and cities in West Java, including Bandung, Cianjur, Bogor, and others ((BNPB, 2025).

Early childhood is a particularly vulnerable stage due to limitations in cognitive and motor skills, as well as the ability to evacuate independently (Niazi et al., 2022); therefore, disaster mitigation education from an early age is crucial to incorporate into learning activities in order to create and foster a sustainable culture of preparedness. Young children are in the preoperational stage, during which they begin to master symbolic abilities through language and role-playing, but still think egocentrically and are not yet fully capable of logical thinking. According to Piaget (Ilhami, 2022), young children in the preoperational stage have limitations in understanding abstract concepts; this condition requires learning to focus on concrete activities and experiences that directly connect them to real phenomena in their surroundings, so the media used in learning must provide realistic simulations.

Immersive pop-up books serve as interactive 3D learning tools that can provide a concrete solution for disaster mitigation education for young children in the preoperational stage. Immersive pop-up books allow children to interact directly by opening pages to view models of cracked buildings, physically observe the shape of cracked ground, and experience movement through interactive illustrations. This approach helps overcome attention span limitations and enables children to focus on a single real-world object.

STEAM (Science, Technology, Engineering, Art, Mathematics) education offers a solution by integrating five elements that align with Piaget's constructivist theory, in which children can learn through direct, active exploration and the manipulation of concrete objects (Alfadhilah, 2025). Using the STEAM approach in education by integrating these five elements can enhance children's holistic development through creative exploration and problem-solving, in line with children's "golden period" of cognitive development (Made et al., 2025).

Research on interactive media for disaster mitigation among early childhood has been conducted by several previous researchers. The Study by Anita, Kurnia, & Chairilsyah (2023) developed an R&D-based earthquake disaster mitigation pop-up book that was proven to be highly viable based on expert validation (Anita et al., 2023). In line with this, Khoirunnisa, Suryati, & Yuliantina (2024) developed the pop-up book "Ayo Siaga Bencana" and received positive feedback from both teachers and children (Khoirunnisa et al., 2025). In addition to pop-up books, Ubaidillah, Putri, Hauri, Yuliani, & Utami (2024) found that the use of lift-the-flap books can increase children's interest and active engagement in disaster mitigation learning (Ubaidillah et al., 2024), a finding later reinforced by Ulfa, Rolina, & Alfina (2024) through a quasi-experimental design that demonstrated a significant effect of using lift-the-flap books on disaster preparedness among 5–6-year-olds (Ulfah et

al., 2024). Furthermore, research on learning approaches by Salma, Putri, & Nikawanti (2020) indicates that integrating STEAM into early childhood education effectively fosters critical thinking and problem-solving through the manipulation of concrete objects (Salma et al., 2023). Nevertheless, there is a significant research gap. Most previous studies on pop-up books have focused on the media development stage (feasibility testing) and improving general readiness, but have not thoroughly examined aspects of conceptual understanding in children at the preoperational stage. Furthermore, no study has yet combined the manipulative advantages of immersive pop-up books with the integration of STEAM elements to reduce the cognitive load associated with conventional video media. Therefore, this study aims to fill this gap by quantitatively testing the effectiveness of STEAM-based immersive pop-up books in transforming verbal knowledge into meaningful conceptual understanding of earthquake disaster mitigation.

Methods

This study employed a quantitative experimental design, specifically a One-Group Pretest-Posttest Design (Creswell & Creswell, 2018). Measurements of the dependent variable (understanding of earthquake disaster mitigation concepts) were taken twice for the same single group: before the treatment (pretest) and after the treatment (posttest) (Sugiono, 2021). The treatment tested in this study was a

learning process on earthquake disaster mitigation using an immersive, STEAM-based pop-up book designed for early childhood education, conducted over five sessions.

The sample comprised 17 children aged 4–6 years (Group B) enrolled at KB Wisana Cidadap in Bandung. The sample size of (N=17) was selected via purposive sampling, constrained by the natural class size of the early childhood center to preserve normal instructional ecological validity and prevent social/emotional stress caused by artificially re-grouping young children (Creswell & Creswell, 2018). While representing a small-scale experimental trial, (N=17) exceeds the minimum requirement (N > 15) for small-sample educational interventions to reliably detect statistical effect sizes (Cohen, 1988).

This test instrument was designed to assess indicators of preoperational conceptual understanding in early childhood, adapted from Jean Piaget's theory (simple classification, serialization/measurement, symbolic representation, schemas, and assimilation-accommodation) (Istiqomah & Maemonah, 2021). Children's responses were assessed using a 1–4 scoring rubric, ranging from the "Not Yet Developed" criterion (score 1) to "Very Well Developed" (score 4). These raw scores were then converted to a standardized scale of 0–100 for analysis. In addition to test methods, non-test techniques such as visual documentation and grade records were also used to support the validity of the research data.

Quantitative data analysis was conducted through several operational stages using IBM SPSS version 30.0. First, a descriptive statistical analysis was performed to determine the mean, minimum, maximum, and standard deviation of the pre-test and post-test scores. Second, a prerequisite test—specifically, a normality test of the data distribution using the Shapiro-Wilk method—was conducted. Third, since the data were found to be normally distributed ($p > 0.05$), a hypothesis test to assess the significance of the difference in performance before and after the intervention was performed using a parametric Paired Sample t-test at a significance level of 0.05. Fourth, to measure the level of effectiveness and the extent of improvement in children's conceptual understanding, the Normalized Gain (N-Gain) value was calculated. Finally, to determine the magnitude of the effect of implementing the STEAM-based immersive pop-up book, an effect size analysis was performed using Cohen's d formula (Cohen, 1988).

Result and Discussions

This study measured the effectiveness of an immersive STEAM-based pop-up book for early childhood education in enhancing children's understanding of earthquake disaster mitigation concepts through two assessment stages: a pre-test and a post-test. Based on data analysis of 17 respondents, the descriptive statistics show an increase in children's cognitive abilities after receiving the treatment. The average

score for children's understanding of disaster mitigation concepts increased significantly from the initial score to the final score.

Table 1 Descriptive Statistics of Pre-test and Post-test Scores

Statistics Descriptive					
	N	Minimum	Maximum	Mean	Std. Deviation
Pre-test	17	48.00	93.00	72.9412	14.54506
Post-test	17	71.00	100.00	87.8824	8.39555

Based on the descriptive statistics, the standard deviation after the treatment decreased quite drastically compared to before the treatment. This indicates that the distribution of children's cognitive ability data after the intervention became more even, narrowing the gap in understanding among children in the classroom.

Before hypothesis testing, the data distribution was tested using the Shapiro-Wilk normality test and was found to be normally distributed ($p > 0.05$), so the analysis continued using parametric statistics. The significance of differences in children's cognitive performance was tested using a paired-sample t-test with IBM SPSS version 30.0.

Table 2 Paired Sample t-Test

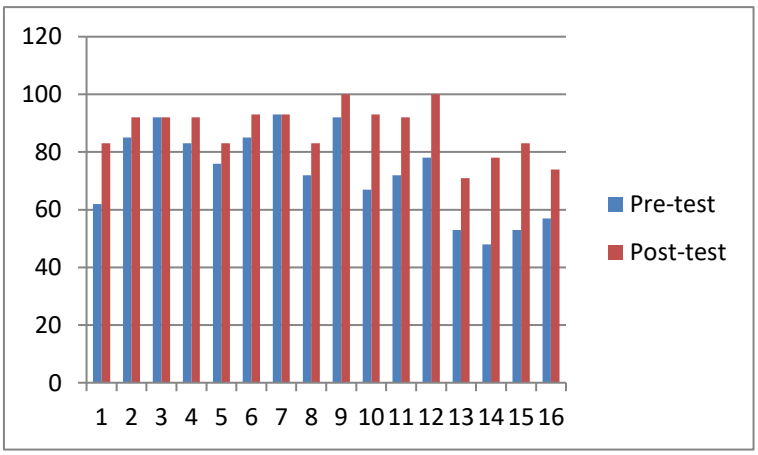
	Mean	t	df	Sig.	Des.
Pre-test Post-test	-14.941	-6.478	16	<0.001	H_0 rejected H_1 accepted

Table 3 N-Gain Analysis Results

	N	Minimum	Maksimum	Mean
N-Gain	17	0.00	1.00	0.5280

Based on the results of the hypothesis test, a significance value of < 0.001 ($p < 0.05$) was obtained, indicating a highly significant difference in children's understanding of disaster mitigation concepts before and after the intervention using interactive media. Thus, the alternative hypothesis (H_1) is convincingly accepted. The Normalized Gain (N-Gain) calculation yielded a coefficient of 0.5280, indicating that the effectiveness of the improvement in children's abilities falls into the "moderate" category. Meanwhile, the effect size analysis yielded a Cohen's d value of 1.571. This value falls within the "very high" effect category, proving that the use of this medium has a significant practical impact in the field.

Figure 1. Pre-test and Post-test Improvement Chart



This significant improvement is due to the fact that the immersive, STEAM-based pop-up book medium is capable of presenting the abstract phenomenon of an earthquake as a concrete, three-dimensional visual representation. For young children in the preoperational stage according to Jean Piaget, this sensory-based learning experience is crucial because children are not yet capable of performing formal logical operations without the stimulus of real objects (Woolfolk, 2016). The book's multi-layered components and dynamic mechanical movements provide children with a controlled space for independent exploration. Based on Cognitive Load Theory, this interactive yet gradual media structure reduces the load on children's short-term working memory. The narrative, which is not too fast-paced—unlike conventional digital video media—helps children optimally assimilate and accommodate new information into their cognitive schemas (Cahyani et al., 2020) .

The integration of the STEAM (Science, Technology, Engineering, Art, and Mathematics) approach in this medium meaningfully stimulates children's critical thinking skills (Montés et al., 2024). Children do not merely memorize verbal disaster instructions; instead, they are encouraged to reason about the causes of earthquakes, understand the functions of safety equipment, and practice self-rescue simulations (drop, cover, and hold on) through logical problem-solving. Thus, this educational resource has proven effective in transforming

passive memorization into a process of developing practical and context-specific disaster mitigation reasoning.

The findings of this study confirm that the use of STEAM-based immersive pop-up books significantly improves young children's understanding of earthquake disaster mitigation concepts. The increase in the average pre-test to post-test score, with an N-gain of 0.5280 (moderate category) and an effect size of 1.496 ($d > 0.8$, very large category), demonstrates the effectiveness of this medium in facilitating children's knowledge reconstruction. The decrease in the variability of children's scores (standard deviation decreased from 14.55 to 8.40) reinforces that this medium is capable of leveling the playing field in terms of understanding among students with various learning styles. This effectiveness aligns with Cognitive Load Theory, in which the combination of visual and tactile stimulation reduces extraneous cognitive load and optimizes information processing at the preoperational stage, in accordance with Piaget's theory of cognitive development.

These empirical findings both challenge and complement the limitations of the five previous studies cited in the introduction. Research by (Anita et al., 2023) and (Khoirunnisa et al., 2025) noted an increase in understanding of mitigation through conventional pop-up books; however, the effect size achieved in this study proved to be higher ($d = 1.496$). This is because the media in the previous studies

relied solely on static paper interactions. On the other hand, compared to the studies by (Ubaidillah et al., 2024) and (Ulfah et al., 2024) which utilized purely digital learning media (such as apps or animated videos), this study excels in maintaining children's sensorimotor engagement. Purely digital media often triggers cognitive overload in young children due to the loss of the tactile dimension. This finding also expands upon the study by (Ulfah et al., 2024) which focused on physical disaster simulations; this study demonstrates that physical simulations integrated into interactive picture stories provide better retention of understanding among children.

The primary novelty distinguishing this research from previous studies lies in three aspects of the hybrid interactive design. First, this medium combines physical 3D tactile manipulation with digital augmentation in the form of QR codes that link to disaster simulation animations on each page.

Figure 2. Pop-up Book



Second, unlike typical disaster pop-up books that merely convey a narrative, this medium systematically integrates the five STEAM

elements for early childhood education: mechanical engineering of folds (Engineering), understanding of geophysical structures (Science), access to animations via QR codes (Technology), visual illustrations (Art), and the recognition of fracture patterns and geometry (Mathematics). Third, this study emphasizes the contextualization of local disaster-related material.

Figure 3. Pop-up Book



Adapting the material to the children's real-world environment has proven to make abstract concepts like "fault displacement" more concrete and relevant for early childhood learners. The practical implications of this study indicate that disaster mitigation education at the early childhood education level can no longer rely solely on lectures or verbal instructions. Early childhood educators can adopt STEAM-based immersive pop-up books as a structured and interactive learning tool for disaster education. However, this study has limitations regarding the sample scope, which was restricted to a single geographic region, as well as the physical durability of the paper pop-up media when used repeatedly without supervision. Future research is

recommended to test the effectiveness of this medium on a larger sample scale and to explore the use of more durable materials.

Conclusion

The use of immersive STEAM-based pop-up books has been proven to be significantly effective in improving young children's understanding of earthquake disaster mitigation concepts. The improvement in children's understanding falls into the moderate category with a very large effect size, while also helping to level out the variability in students' comprehension levels. The uniqueness of this medium lies in its success in integrating three-dimensional physical manipulation with digital interactivity via QR codes, the comprehensive application of the five-element STEAM approach for early childhood education, and the adaptation of the material to local geophysical fault threats. This combination has proven effective in reducing children's cognitive load and facilitating the reconstruction of concrete knowledge in children at the preoperational stage. The practical implications of this study underscore the importance of shifting mitigation education strategies at the early childhood education level from conventional verbal instructional methods toward interactive and kinesthetic hybrid learning media. This medium can be adopted by early childhood educators and disaster management agencies as a structured, contextual, and enjoyable early childhood education tool. This study has limitations regarding its subject scope, which was

restricted to a single region, as well as the physical durability of the paper used in the pop-up media. Therefore, future research is recommended to test the effectiveness of this medium on a broader and more diverse sample scale, as well as to explore the use of more durable interactive materials.

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