Jurnal Ilmiah Multidisiplin
Vol.4, No.1, January 2027, hal.90-104
e-ISSN: 3031-769X
DOI: 10.62282/juilmu.v4i1.90-104
https://jurnal.yayasanyutapendidikancerdas.com/index.php/juilmu

Submitted on 24/09/2026;
Revised on 02/10/2026;
Accepted on 02/11/2026;

Knowledge Meets Readiness: Integrating an Early Warning System into Disaster Education for Students in Coastal Banten, Indonesia

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Abstract
The coastal areas of Cinangka District, Serang Regency, are exposed to earthquake and tsunami hazards and were affected by the 2018 Sunda Strait tsunami. This study evaluated the immediate knowledge outcomes and implementation feasibility of Knowledge Meets Readiness, a school-based disaster education program that integrates an earthquake and tsunami early warning system into classroom learning. A pre-experimental program evaluation using a one-group pretest and posttest design was conducted with 40 elementary school students in grades three to six at SDN 1 Pasauran. The intervention included interactive learning materials, educational videos, earthquake-prop simulations, a demonstration of an early warning system provided by PT. TOA Indonesia, and an evacuation drill triggered by the warning system. Knowledge was assessed using a 12-item multiple-choice test scored on a scale from zero to one hundred. The mean score increased from 67.50 with a standard deviation of 18.57 at pretest to 78.12 with a standard deviation of 19.40 at posttest, representing an average increase of 10.62 points. Statistical analysis indicated that this increase was significant, with a moderate to large effect size. Exploratory analyses showed no significant differences in knowledge gains based on grade level or gender. At the item level, significant improvement was found only for the item concerning the causes of earthquakes, while the item related to earthquake types remained the most difficult. These findings suggest that integrating a functional early warning system into elementary disaster education is feasible and may improve students' short-term knowledge. Further studies using controlled designs, delayed posttests, and behavioral measures are recommended to determine its effectiveness and contribution to disaster preparedness.

Keywords: early warning system; earthquake knowledge; elementary school students; one-group pretest-posttest; school-based disaster education

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INTRODUCTION

Indonesia lies at the convergence of the Indo-Australian, Eurasian (Sunda), and Pacific plates, making it one of the countries with the highest levels of seismic activity and geological disaster risk in the world, particularly from earthquakes and tsunamis (Marlina et al., 2024; Reid & Mooney, 2022; Triyanti et al., 2023). Along the southern margin of Sumatra and Java, the Indo-Australian Plate is subducted beneath the Sunda Plate along the Sunda subduction zone, and the megathrust segment off the southern coast of West Java and southeast Sumatra has been identified as having the potential to generate large earthquakes and tsunamis (Supendi et al., 2022). The Sunda Strait, which separates Java and Sumatra and borders the coast of Serang Regency, is also exposed to volcanic tsunamis from the Anak Krakatau volcano, as shown by the flank-collapse tsunami of 22 December 2018 (Muhari et al., 2019). These seismic and volcanic tsunami sources make the Serang coast a highly relevant setting for school-based earthquake and tsunami education.

Earthquakes have the potential to cause loss of life, damage infrastructure, and disrupt social and economic activities. It is important to distinguish between prediction and early warning. Earthquakes cannot be predicted deterministically; that is, their time, location, and magnitude cannot be specified in advance. Earthquake early warning, by contrast, detects an earthquake that has already started and issues alerts seconds before strong shaking

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arrives at a given location (Allen & Melgar, 2019), while tsunami warnings are issued after a potentially tsunamigenic event has been detected and can provide additional lead time before the waves reach the coast (Šakić Trogrlić et al., 2022). In coastal areas, warning lead times may be very short, and the 2018 Sunda Strait tsunami arrived without preceding earthquake shaking as a natural warning sign (Widiyanto et al., 2020). Therefore, coastal communities need to recognize warnings and take quick and appropriate rescue measures (Doondori et al., 2023; Hoffmann & Muttarak, 2017; Pradhananga et al., 2022; Rajeswari et al., 2025). In the program evaluated in this study, the EWS functions as a warning tool rather than a prediction tool: students learn to recognize the warning siren and practice the actions to be taken after it is activated.

One community group that is vulnerable to disasters is the school community. Schools not only serve as places for learning but also serve as gathering places for large numbers of children. Elementary school-aged children have limited capacity to understand disaster threats and make independent decisions in emergencies. Without adequate knowledge and skills, this group is at greater risk than other age groups (Atkinson & Fowler, 2023; Fu & Zhang, 2024; Mutch, 2023; Opabola et al., 2023).

Serang Regency, particularly the Cinangka District, is a coastal area prone to earthquakes and tsunamis due to its proximity to the Sunda Strait. The 2018 Sunda Strait tsunami killed 437 people, with surveyed run-up heights of up to 13.5 m (Muhari et al., 2019), and post-event field surveys recorded tsunami run-up and inundation along the Serang coast, including at Pasauran Village in Cinangka District (Widiyanto et al., 2020). Experiences of various earthquakes and tsunamis in Indonesia demonstrate that schools in coastal areas require a more comprehensive preparedness system, not only through the availability of mitigation infrastructure but also through capacity building for school residents in understanding disaster characteristics and self-rescue procedures (Akhirianto et al., 2025; Heriati et al., 2024; Supendi et al., 2022).

In recent decades, disaster education has developed as an effective non-structural strategy for enhancing community capacity to respond to disasters. Various studies have shown that increasing knowledge about hazard characteristics, disaster mechanisms, and mitigation measures can improve individual and community preparedness in responding to emergencies (Indrawijaya et al., 2023; Solarino et al., 2025; Suparji et al., 2026). In schools, disaster education aims not only to increase students' knowledge of basic disaster concepts but also to shape attitudes, awareness, and decision-making skills when facing emergency situations. Education provided from an early age is expected to foster a culture of disaster awareness that will continue into adulthood (Saryono et al., 2026; Scolobig & Balsiger, 2024).

However, the implementation of disaster education in schools still faces various challenges. A methodological review of disaster education programs for children found that most programs and their evaluations focus on knowledge of hazards and protective actions, with very limited evidence on how programs strengthen children's self-protective capacities (Johnson et al., 2014). In Indonesia, an evaluation of school-based disaster risk reduction education involving children, school personnel, and non-governmental organizations identified barriers such as limited integration into the formal curriculum, dependence on short-term externally funded projects, and limited teacher capacity (Amri et al., 2017). A scoping review of disaster preparedness education likewise noted that learning materials tend to emphasize definitions and theory rather than practical exercises (Guo et al., 2025). At SDN 1 Pasauran, based on initial survey to the headmaster and several teachers, the learning about earthquake/tsunami topics were thaught only through classroom without any drills or Early Warning System (EWS)-based acitivities.

Various experiential learning approaches have been developed to address these limitations. The use of visual media, educational videos, disaster simulations, educational games, and evacuation drills has been shown to increase student engagement during the learning process while strengthening knowledge retention. Reviews of preparedness programs for children and families indicate that interactive programs grounded in theory and evidence tend to produce better outcomes (Ronan et al., 2015), simulation-based learning has been used to provide realistic practice in disaster risk management education (Tasantab et al., 2023), and context-based science learning has helped children develop more scientific explanations of earthquakes and tsunamis (Cabello, 2022). Therefore,

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integrating various learning methods is a promising approach to improving the effectiveness of disaster education in schools (Kristyanto, Bahri, et al., 2025; Kristyanto, Rahmawati, et al., 2025).

In addition to capacity building through education, disaster risk reduction efforts also require support from mitigation technology, one of which is the implementation of an Early Warning System (EWS). Early warning systems are designed to provide the public with rapid information about potential disaster threats, providing sufficient time to take emergency rescue measures. However, the effectiveness of an early warning system is determined not only by the sophistication of the technology used, but also by the public's ability to understand the meaning of the warnings received and the immediate actions to be taken after the alarm sounds. In other words, early warning technology will not provide optimal benefits unless accompanied by increased community capacity through ongoing education and training (Clegg et al., 2022; Hermans et al., 2022; Sufri et al., 2020; Zhang & Lu, 2025).

In this study, Creative Hazard Education (CREDO) refers to a school-based hazard education approach developed by the Geology Study Program, Universitas Indonesia that combines (1) contextual geological hazard content, (2) creative learning media such as visual materials, videos, and educational games, and (3) participatory, experience-based activities such as simulations, with the objective of improving students' hazard knowledge and engagement. CREDO-based curricula have previously been implemented and evaluated for tsunami awareness among students in Serang and for landslide mitigation among high school students in Depok (Kristyanto, Bahri, et al., 2025; Kristyanto, Rahmawati, et al., 2025). The Knowledge Meets Readiness (KMR) program inherits from CREDO its contextual hazard content, interactive learning materials, educational videos, and prop-based simulations. KMR adds three new elements: (1) a technical demonstration of a functional earthquake–tsunami EWS, (2) an evacuation drill triggered by the EWS siren, and (3) an evaluation design that includes item-level analysis of a knowledge test.

Various previous studies have evaluated the effectiveness of disaster education and early warning system implementation separately. Some studies focused on improving students' knowledge after participating in disaster training, while others focused on developing early warning system technology (Atkinson & Fowler, 2023; Šakić Trogrlić et al., 2022; Samarakkody et al., 2023; Saryono et al., 2026). To the best of our knowledge, the published CREDO implementations did not incorporate a functional EWS into the learning process (Kristyanto, Bahri, et al., 2025; Kristyanto, Rahmawati, et al., 2025), and a systematic review of community engagement in disaster EWSs found a lack of reported engagement activities across the EWS elements and insufficient incorporation of such activities into formal warning systems (Sufri et al., 2020).

Therefore, this study aimed to evaluate the immediate knowledge outcomes and implementation feasibility of the KMR program among elementary school students in a tsunami-affected coastal area. Specifically, the study examined (1) changes in overall knowledge scores from pretest to posttest, (2) whether knowledge gains differed by grade level and gender (exploratory analyses), and (3) item-level changes indicating which concepts were and were not mastered. Preparedness behaviors, such as siren recognition, correct action sequences, evacuation time, and route choice, were not measured and are beyond the scope of this study.

The novelty of this study lies in integrating a functional earthquake–tsunami warning siren into a classroom-based disaster education sequence for elementary students and in evaluating outcomes at the item level. Its contribution is to provide initial evidence on the feasibility and immediate knowledge outcomes of EWS-integrated disaster education and to identify concepts that require improved instruction and assessment.

METHODS

Study Area

This research was conducted at SDN 1 Pasauran, located in Cinangka District, Serang Regency, Banten Province, Indonesia (Figure 1). The school is located on the coast of the Sunda Strait, less than 500 m from the the shoreline, and was selected for three reasons. First, the area is exposed to earthquake and tsunami hazards from the Sunda megathrust and the Anak Krakatau volcano (Muhari et al., 2019; Supendi et al., 2022). Second, Pasauran

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Village was among the coastal areas affected by the 2018 Sunda Strait tsunami (Widiyanto et al., 2020). Third, the school had not previously received structured disaster education or EWS-based drills program.

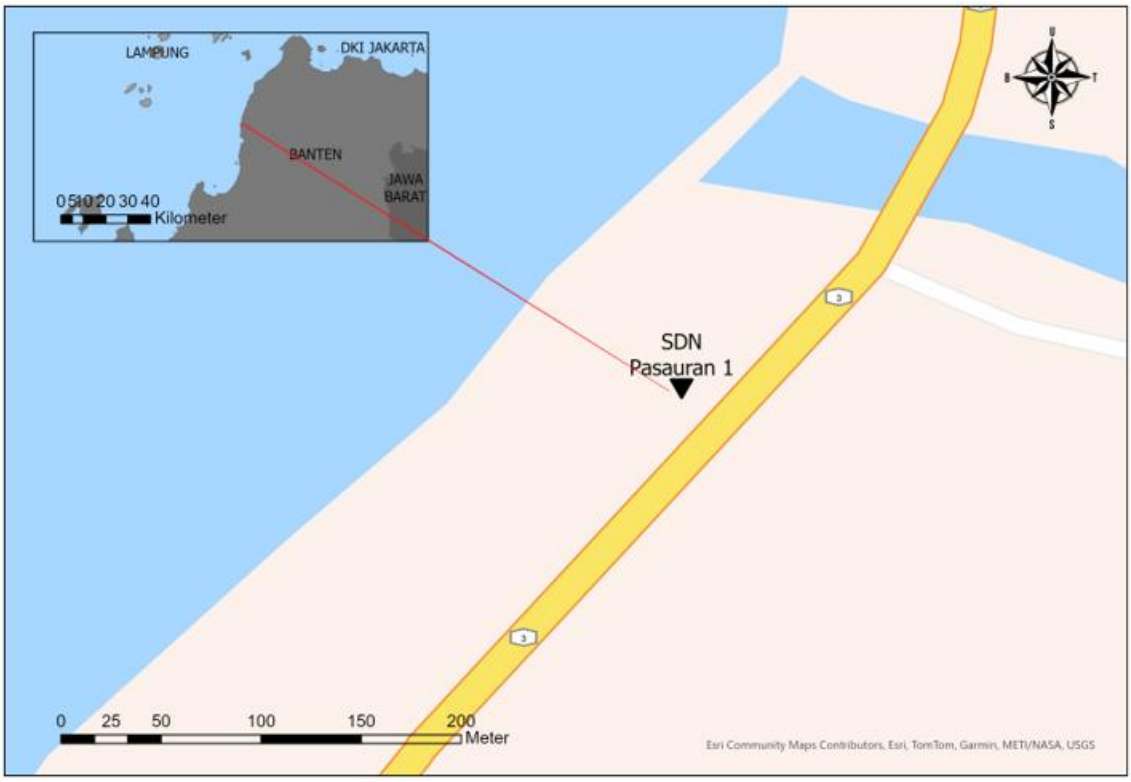


Figure 1. Location map of SDN 1 Pasauran, Cinangka District, Serang Regency
Source: (Research Data, 2026)

Research Design and Participants

This study used a pre-experimental program evaluation design with a one-group pretest–posttest (Creswell & Creswell, 2018). No qualitative data were collected, and the program was implemented in a single cycle without iterative reflection; therefore, the study is not framed as qualitative research or action research. All participants completed the same knowledge test before and after the program so that changes in knowledge could be compared. Because there was no control group, the observed changes are interpreted as within-group changes associated with the program rather than as causal effects (Shadish et al., 2002).

A total of 40 students participated in this study. Participants were selected by the school based on their ability to participate in all educational activities and simulations. The participants comprised two third-grade students (5%), four fourth-grade students (10%), 16 fifth-grade students (40%), and 18 sixth-grade students (45%). Based on gender, participants comprised 26 female students (65%) and 14 male students (35%). Students' ages ranged from 9 to 12 years old. The subject demographic information is shown in Table 1, while the distribution of the students by grade and sex is presented in Figure 2 and Figure 3, respectively.

Table 1. Participant characteristics (N = 40)

Characteristic	Category	n	Percentage (%)
Sex	Male	14	35
	Female	26	65
Grade	III	2	5
	IV	4	10
	V	16	40
	VI	18	45

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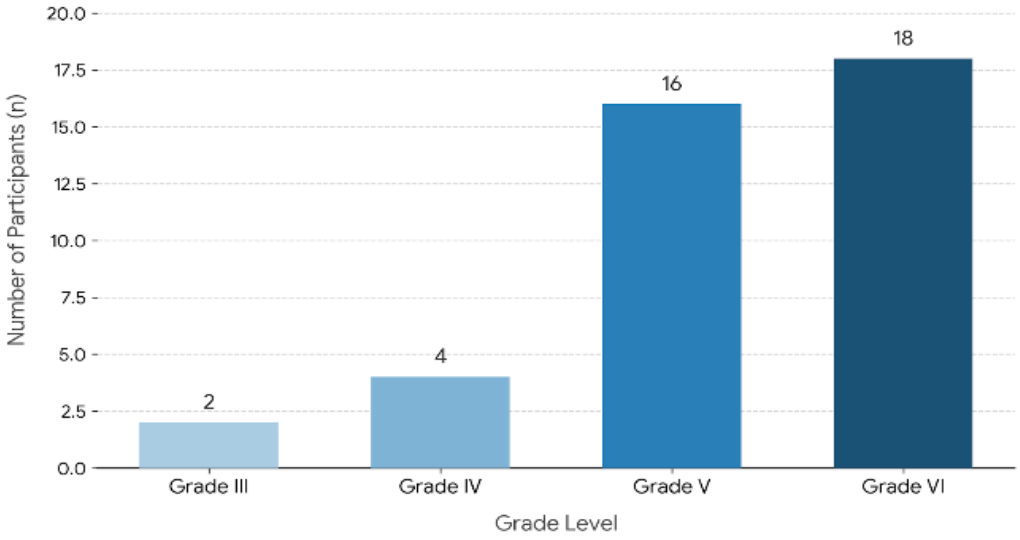


Figure 2. Number of Participants by Grade

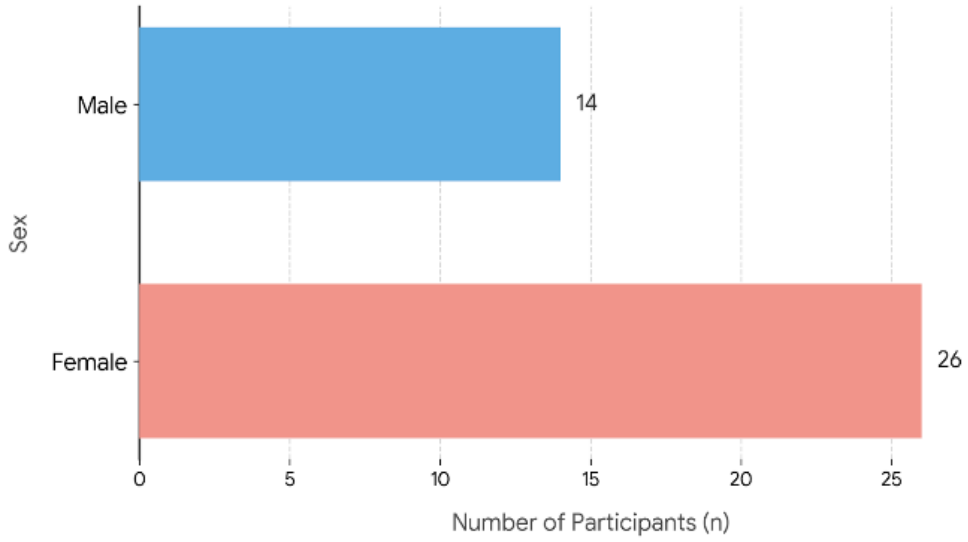


Figure 3. Number of Participants by Sex

Research Instrument

Knowledge was measured using a researcher-developed test consisting of 12 multiple-choice items with 4 answer options, developed from the KMR learning materials. The same test was administered as the pretest and the posttest. The test blueprint, which maps each item to its domain, sub-concept, learning objective, and the KMR component in which the content was delivered, is presented in Table 2. Items with the same domain label measure different sub-concepts, as specified in the table. Each correct answer was scored 1 and each incorrect answer 0, and the total score was converted to a 0–100 scale (number of correct answers ÷ 12 × 100), so that a score of 100 indicates that all 12 items were answered correctly.

Before use, the test was reviewed by experts (university lecturers) to establish content validity, namely the relevance of each item to the learning objectives and the suitability of its language for elementary school students.

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The instrument was not pilot-tested before the study; therefore, its psychometric properties were estimated post hoc from the study data. Internal consistency (KR-20) was 0.64 for the pretest and 0.76 for the posttest, indicating moderate reliability for a short test. Item difficulty (proportion correct) and discrimination (corrected item–total correlation) are reported in Table 9; in the pretest, four items (items 1–4) had discrimination values below 0.20, indicating weak discrimination. These limitations are taken into account when interpreting the item-level results.

Table 2. Test blueprint: item, domain, sub-concept, learning objective, and KMR component

Item	Domain	Sub-concept measured	Learning objective	KMR component
1	Definition of earthquake	Meaning of an earthquake as sudden shaking of the ground	Students can define an earthquake	Interactive materials
2	Causes of earthquake	Tectonic setting: Indonesia lies at the junction of several tectonic plates	Students can explain why earthquakes frequently occur in Indonesia	Interactive materials; earthquake props
3	Causes of earthquake	Volcanic eruption as a source of earthquakes	Students can identify natural phenomena that cause earthquakes	Interactive materials
4	Types of earthquakes	Tectonic earthquake as an earthquake caused by plate movement	Students can name the type of earthquake caused by plate movement	Interactive materials; earthquake props
5	Impacts of earthquake	Damage to buildings (building collapse)	Students can identify the impacts of earthquakes	Educational videos
6	Hazard zone identification	Coastal areas as tsunami hazard zones after an earthquake	Students can explain why coastal areas must be avoided after an earthquake	EWS demonstration; evacuation simulation
7	Pre-disaster mitigation	Knowing the evacuation route	Students can identify preparedness actions before an earthquake	Evacuation simulation
8	Pre-disaster mitigation	Securing furniture and objects in the classroom	Students can describe ways to make the classroom safer before an earthquake	Educational videos
9	During-disaster mitigation	Self-protection indoors (taking cover under a sturdy table)	Students can choose the correct action when an earthquake occurs in the classroom	Earthquake props; evacuation simulation
10	During-disaster mitigation	Self-protection outdoors (moving to an open area)	Students can choose the correct action when an earthquake occurs outdoors	Educational videos
11	During-disaster mitigation	Moving away from the shore when an earthquake occurs at the beach	Students can choose the correct action when an earthquake occurs at the beach	EWS demonstration; evacuation simulation
12	Post-disaster mitigation	Avoiding damaged buildings because of aftershocks	Students can explain why damaged buildings must not be entered after an earthquake	Interactive materials

Intervention Protocol

The Knowledge Meets Readiness (KMR) program was delivered according to a six-stage intervention protocol (Figure 4): (1) a pretest; (2) delivery of interactive educational materials on earthquakes, tsunamis, and mitigation measures; (3) screening of educational videos on mitigation measures; (4) hands-on simulations using earthquake props combined with a technical demonstration of the earthquake–tsunami EWS provided by PT. TOA Indonesia; (5) an evacuation simulation in which students responded to the EWS siren; and (6) a posttest. All 40 participants took part in every stage. The program was conducted on 30 July 2026, and the posttest was administered immediately after the activities on the same day.

The program was implemented through a collaboration between the Geology Study Program, Faculty of Mathematics and Natural Sciences, Universitas Indonesia, and PT. TOA Indonesia, with the participation of SDN 1 Pasauran. The roles of each partner are summarized in Table 3.

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Table 3. Roles of the partners in the KMR program

Partner	Role	Contribution
Geology Study Program, FMIPA, Universitas Indonesia	Program developer and implementer	Developed the KMR materials and the knowledge test, delivered the learning sessions, and collected and analyzed the data.
PT. TOA Indonesia	Technology partner	Provided the earthquake-tsunami EWS equipment and supported its demonstration and operation during the evacuation simulation.
SDN 1 Pasauran	Host school	Selected the participants, provided the venue and schedule, and supported the evacuation drill.

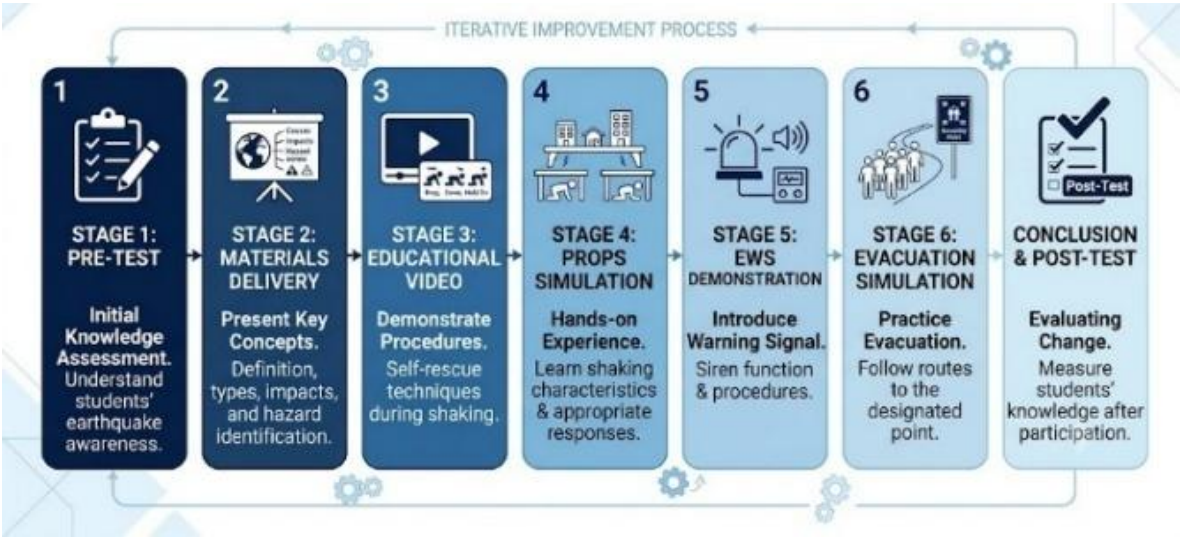


Figure 4. Workflow of Knowledge Meets Readiness Program

Data Analysis

Data were analyzed using Python 3.12 with the SciPy library (version 1.17). Scores were expressed on a 0–100 scale as the percentage of the 12 items answered correctly, and all scores, including gain scores (posttest minus pretest), were computed from individual raw scores before averaging. Descriptive statistics included the mean, standard deviation (SD), 95% confidence interval (CI), median and interquartile range (IQR), and minimum and maximum. Normality was examined using the Shapiro–Wilk test. The pretest–posttest change was tested using a paired-samples t-test, and the mean difference, its 95% CI, and Cohen's dz (mean gain divided by the SD of the gains) were reported; because the posttest scores were not normally distributed, the Wilcoxon signed-rank test was used as a robustness check.

Differences in gains by grade level (one-way ANOVA with η^2) and by gender (independent samples t-test with Levene's test, Welch's correction, and Hedges' g) were treated as exploratory because of the small and unequal subgroup sizes, and baseline comparability was checked by comparing pretest scores between groups. Item-level changes were tested using exact McNemar tests for paired dichotomous data, with Holm's correction for 12 comparisons. Item difficulty, item discrimination, and KR-20 reliability were calculated as described above (Field, 2018). The term "statistically significant" is used only for results supported by a statistical test ($\alpha = 0.05$).

RESULTS AND DISCUSSION

The Improvement of Students' Knowledge

Overall Improvement

All 40 students completed the pretest, the KMR activities, and the posttest. Table 4 summarizes the pretest, posttest, and gain scores. The mean score increased from 67.50 (SD = 18.57; 95% CI [61.56, 73.44]) to 78.12 (SD

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= 19.40; 95% CI [71.92, 84.33]), and the mean difference was 10.62 points (SD = 14.49; 95% CI [5.99, 15.26]). The pretest scores (W = 0.951, p = 0.084) and the gain scores (W = 0.966, p = 0.257) did not deviate significantly from normality, whereas the posttest scores did (W = 0.817, p < 0.001), reflecting the clustering of scores near the maximum. The paired-samples t-test indicated a statistically significant increase, t (39) = 4.64, p < 0.001, with a medium-to-large effect size (dz = 0.73, 95% CI [0.38, 1.08]); the Wilcoxon signed-rank test led to the same conclusion (p < 0.001).

Table 4. Pretest, posttest, and gain scores (N = 40; possible range 0–100)

Score	Mean (SD)	95% CI	Median (IQR)	Min–Max
Pretest	67.50 (18.57)	61.56–73.44	66.67 (58.33–75.00)	25.00–100.00
Posttest	78.12 (19.40)	71.92–84.33	83.33 (75.00–91.67)	25.00–100.00
Gain (post − pre)	10.62 (14.49)	5.99–15.26	8.33 (0.00–18.75)	−25.00–41.67

Note. Paired-samples t-test: t(39) = 4.64, p < 0.001; mean difference = 10.62, 95% CI [5.99, 15.26]; Cohen's dz = 0.73, 95% CI [0.38, 1.08]. Wilcoxon signed-rank test: p < 0.001. Gain scores were computed for each student before averaging.

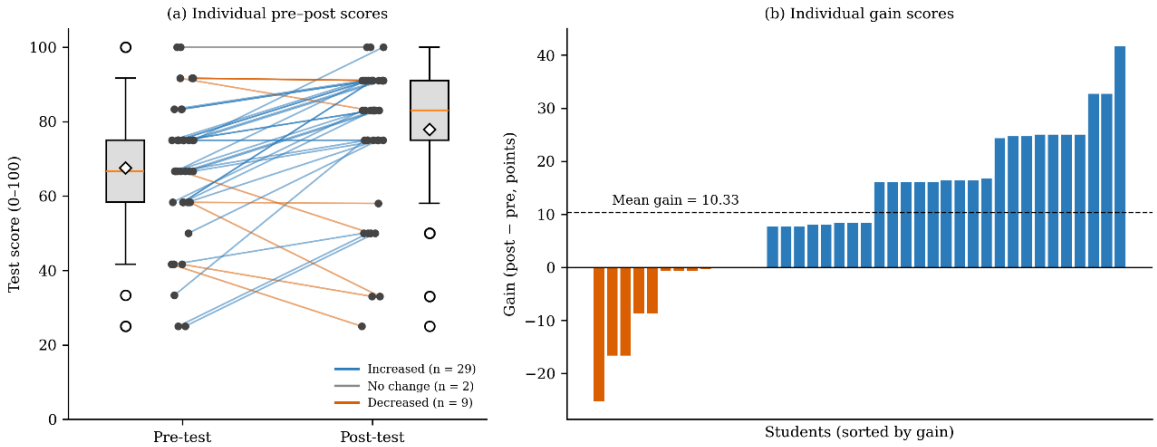


Figure 5. Individual pretest and posttest scores (a) and individual gain scores (b). Scores are the percentage of the 12 items answered correctly (0–100); lines connect each student's pretest and posttest scores

Figure 5 shows the direction of change for each student. Of the 40 students, 27 (67.5%) obtained a higher posttest score, 8 (20.0%) obtained the same score, and 5 (12.5%) obtained a lower score. The median score increased from 66.67 (IQR 58.33–75.00) to 83.33 (IQR 75.00–91.67). Because no mastery criterion was defined a priori, the scores were not classified into performance categories.

Exploratory Comparison by Grade Level

Pretest, posttest, and gain scores by grade level are presented in Table 5. Pretest scores did not differ significantly across grade levels, F(3, 36) = 0.36, p = 0.784, indicating comparable baselines. Mean gains were positive in all grades, ranging from 8.85 points (grade V) to 18.75 points (grade IV); however, the 95% CIs were wide, particularly for grades III (n = 2) and IV (n = 4).

Table 5. Pretest, posttest, and gain scores by grade level, mean (SD)

Grade	n	Pretest	Posttest	Gain	95% CI of gain
III	2	54.17 (17.68)	66.67 (23.57)	12.50 (5.89)	−40.44 to 65.44
IV	4	66.67 (16.67)	85.42 (4.17)	18.75 (18.48)	−10.65 to 48.15
V	16	68.75 (11.59)	77.60 (20.80)	8.85 (15.05)	0.83 to 16.87
VI	18	68.06 (24.13)	78.24 (20.44)	10.19 (14.16)	3.14 to 17.23

Note. Gain scores were computed for each student before averaging; therefore, mean gains may differ by up to 0.01 from the difference between the rounded pretest and posttest means.

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Table 6. One-way ANOVA of gain scores by grade level

Test	F	df	p-value	η^2	Interpretation
One-way ANOVA	0.495	3, 36	0.688	0.04	Not significant

The one-way ANOVA (Table 6) showed no statistically significant difference in gains across grade levels, $F(3, 36) = 0.50$, $p = 0.688$, $\eta^2 = 0.04$. Variances were homogeneous (Levene's $F = 0.53$, $p = 0.664$), and the Kruskal–Wallis test gave a consistent result ($p = 0.435$). Because the ANOVA was not significant, no post-hoc comparisons were performed. Given the very small grade III and IV groups, this analysis is exploratory and had limited power to detect differences.

Exploratory Comparison by Gender

Gender comparisons were also treated as exploratory (Table 7). Baseline scores were comparable between male ($M = 69.64$, $SD = 15.54$) and female students ($M = 66.35$, $SD = 20.20$), $t(38) = 0.53$, $p = 0.599$. The mean gain was 5.95 points ($SD = 14.03$; 95% CI [−2.15, 14.05]) for male students and 13.14 points ($SD = 14.37$; 95% CI [7.34, 18.95]) for female students.

Levene's test indicated homogeneous variances ($F = 0.02$, $p = 0.890$). The independent samples t-test showed no statistically significant difference in gains, $t(38) = −1.52$, $p = 0.136$ (Welch's $t(27.30) = −1.53$, $p = 0.137$), although the difference corresponded to a small-to-medium effect size (Hedges' $g = −0.49$; mean difference = −7.19, 95% CI [−16.76, 2.38]) (Table 8). Given the unequal group sizes and limited power, the absence of a significant difference should not be interpreted as evidence that gains were equivalent for male and female students.

Table 7. Pretest, posttest, and gain scores by gender, mean (SD)

Gender	n	Pretest	Posttest	Gain	95% CI of gain
Male	14	69.64 (15.54)	75.60 (21.05)	5.95 (14.03)	−2.15 to 14.05
Female	26	66.35 (20.20)	79.49 (18.74)	13.14 (14.37)	7.34 to 18.95

Table 8. Comparison of gain scores by gender

Test	t	df	p-value	Interpretation
Levene's test	$F = 0.02$	1, 38	0.890	Equal variances
Independent samples t-test	−1.52	38	0.136	Not significant
Welch's t-test	−1.53	27.30	0.137	Not significant

Note. Hedges' $g = −0.49$; mean difference (male − female) = −7.19, 95% CI [−16.76, 2.38].

Item-Level Results

The test instrument and blueprint are described in the Methods (Research Instrument; Table 2). Table 9 presents, for each item, the number of incorrect answers, item difficulty, discrimination, and the exact McNemar test. Descriptively, the largest decreases in incorrect answers occurred for item 2 (causes of earthquakes; from 23 to 10 students), item 3 (causes of earthquakes; from 20 to 11), and item 6 (hazard zone identification; from 13 to 5). The McNemar test confirmed a statistically significant improvement only for item 2: 13 students changed from an incorrect to a correct answer and none changed in the opposite direction ($p < 0.001$; Holm-adjusted $p = 0.003$). The improvement in item 6 was significant before correction ($p = 0.021$) but not after Holm correction, and the change in item 3 did not reach significance ($p = 0.057$).

Several items showed small descriptive changes. For items 1, 5, 7, 9, 11, and 12, only 5–7 students answered incorrectly in the pretest (difficulty ≥ 0.82), so there was little room for improvement (ceiling effect). Item 10 (during-disaster mitigation) showed an increase in incorrect answers from 9 to 11 students, but this change was not statistically significant ($p = 0.727$), as five students changed from correct to incorrect and three from incorrect to correct. Item 4 (types of earthquakes) had the highest number of incorrect answers in both the pretest (34 students; 85%) and the posttest (27 students; 67.5%), the change was not statistically significant ($p = 0.109$), and

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its pretest discrimination was very low (0.04).

Table 9. Item-level results: incorrect answers, difficulty, discrimination, and McNemar test

Item	Domain	Incorrect (pre)	Incorrect (post)	Reduction	Difficulty (pre)	Difficulty (post)	Discrimination (pre)	McNemar p
1	Definition of earthquake	6	3	+3	0.85	0.93	0.19	0.453
2	Causes of earthquake	23	10	+13	0.43	0.75	0.18	< 0.001*
3	Causes of earthquake	20	11	+9	0.50	0.72	−0.08	0.057
4	Types of earthquakes	34	27	+7	0.15	0.32	0.04	0.109
5	Impacts of earthquake	7	5	+2	0.82	0.88	0.43	0.688
6	Hazard zone identification	13	5	+8	0.68	0.88	0.32	0.021
7	Pre-disaster mitigation	6	4	+2	0.85	0.90	0.37	0.625
8	Pre-disaster mitigation	20	17	+3	0.50	0.57	0.46	0.549
9	During-disaster mitigation	5	2	+3	0.88	0.95	0.30	0.375
10	During-disaster mitigation	9	11	−2	0.78	0.72	0.33	0.727
11	During-disaster mitigation	5	4	+1	0.88	0.90	0.38	1.000
12	Post-disaster mitigation	7	5	+2	0.82	0.88	0.54	0.727

Note. Difficulty = proportion of students answering correctly. Discrimination = corrected item–total correlation in the pretest. McNemar p = exact test based on individual responses; * statistically significant after Holm correction for 12 comparisons (adjusted p = 0.003).

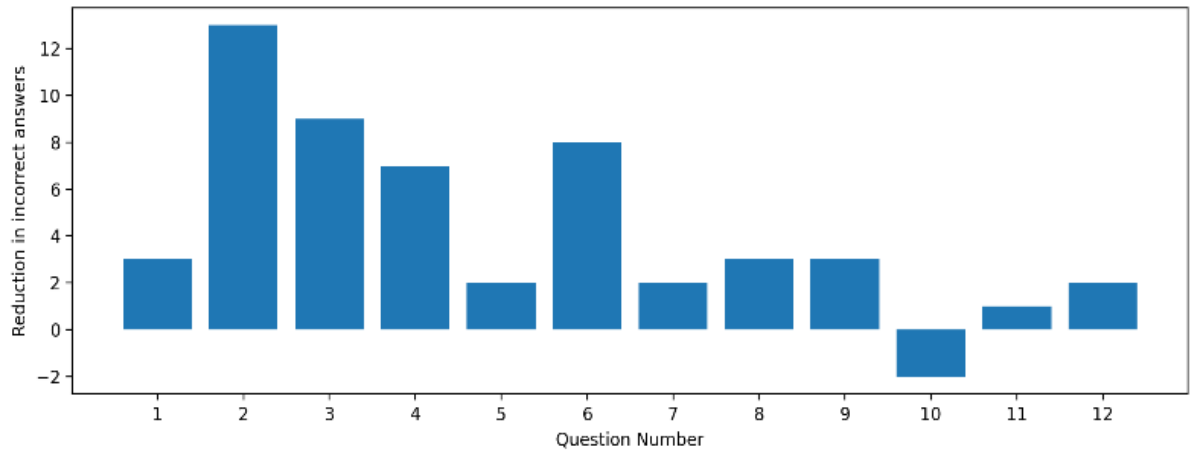


Figure 6. Improvement by question (pre-test vs post-test)

Immediate Knowledge Outcomes of KMR

The results show that students' knowledge scores increased immediately after the KMR program, with a mean gain of 10.62 points and a medium-to-large effect size (dz = 0.73). This pattern is consistent with reviews of disaster education programs for children, in which most evaluations report improvements in children's knowledge after participation (Johnson et al., 2014; Ronan et al., 2015). However, the posttest mean of 78.12 shows that

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mastery was not complete, and knowledge gains do not necessarily translate into protective behavior (Johnson et al., 2014). Moreover, because a one-group design was used and the same items were administered twice, part of the observed gain may reflect testing effects or other influences rather than the program alone (Shadish et al., 2002).

Because the materials, videos, props, EWS demonstration, and evacuation drill were delivered as a single package, this study cannot identify which component drove the observed changes. A plausible explanation, which was not tested, is provided by experiential learning theory, according to which learning is strengthened when concrete experience is combined with reflection and active experimentation (Kolb, 1984). Consistent with this view, context-based science learning has been found to help children develop more scientific explanations of earthquakes and tsunamis (Cabello, 2022), and interactive, participatory disaster education has been associated with greater student engagement (Kristyanto, Bahri, et al., 2025; Kristyanto, Rahmawati, et al., 2025). Future studies should include a process evaluation (e.g., implementation fidelity, student engagement, and observation of drill performance) or a factorial or component design to determine the contribution of each KMR component.

Furthermore, the integration of the Early Warning System (EWS) distinguishes KMR from programs that focus only on knowledge. Reviews indicate that few children's disaster education programs connect knowledge to how children respond to an actual warning (Johnson et al., 2014; Ronan et al., 2015), and studies of school-based disaster education in Indonesia have focused mainly on curriculum integration, teacher roles, and program sustainability (Amri et al., 2017; Saryono et al., 2026). Nevertheless, because this study did not include a comparison group receiving education without EWS integration and did not measure students' responses to the siren, the present data cannot show that EWS integration produces greater knowledge or preparedness gains than education alone.

Item-Level and Subgroup Findings

The item-level analysis indicates that learning outcomes were not uniform across the material. The only statistically significant improvement after correction for multiple comparisons was in item 2 (causes of earthquakes), while items 3 and 6 showed the next-largest descriptive decreases in incorrect answers but did not reach significance after correction. These results suggest that the causes of earthquakes were the content most clearly learned during the program, although the small number of discordant responses for most items limited the power of the item-level tests.

Item 4 (types of earthquakes) remained the most difficult item. The evidence from this study shows that only 15% of students answered this item correctly in the pretest (difficulty = 0.15), a non-significant change ($p = 0.109$), and very weak discrimination (0.04). Several explanations are plausible but could not be tested with the present data. The concept may be more abstract for children, which is consistent with research showing that elementary students describe earthquakes mainly in terms of ground shaking and damage and sometimes confuse earthquakes with volcanoes (Ross & Shuell, 1993), and that alternative ideas about tsunami causes can persist during instruction (Cabello, 2022). However, the weak discrimination of the item also suggests that its wording or answer options may have been unclear, that there may have been a mismatch between the material delivered and the content of the item, or that a floor effect occurred. The same caution applies to item 10, whose increase in incorrect answers was not statistically significant. Future implementations should review the wording of these items and verify their alignment with the learning materials before attributing the errors to conceptual difficulty.

Analysis based on participant characteristics indicates that knowledge gains occurred across all grade levels and across both genders. The exploratory tests did not show statistically significant differences, but the small subgroup sizes, wide confidence intervals, and a small-to-medium effect size for gender mean that these results should not be interpreted as evidence that the program is equally effective for all groups.

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Implications and Future Development

The findings suggest that integrating an EWS into school-based disaster education is feasible in an elementary school setting and is associated with immediate knowledge gains. KMR extends the CREDO approach by linking hazard knowledge to an operational warning signal and an evacuation drill. However, the scalability of KMR has not yet been tested, because the data come from a single implementation at one school. Whether KMR can be scaled up should be treated as a question for future research that considers resource requirements, teacher training, the availability, cost, and maintenance of EWS equipment, alignment with the school curriculum, implementation fidelity, and transferability to schools with different hazard exposures and characteristics.

Another feature of this program is the collaboration among a university, a school, and an industry partner. As summarized in Table 3, Universitas Indonesia developed and delivered the educational content, PT. TOA Indonesia provided and operated the early warning system used during the simulation, and SDN 1 Pasauran hosted the program. Local government agencies were not involved in this implementation. This experience suggests that school preparedness activities may benefit from both educational and technological support; however, the value of such collaboration for sustained implementation remains to be evaluated.

However, this study has several limitations. First, the absence of a control group means that the observed increase cannot be attributed with certainty to KMR; testing effects from repeated items, concurrent influences such as the novelty of the activities, and regression toward the mean cannot be ruled out (Shadish et al., 2002). Second, the instrument was not pilot-tested, its reliability was only moderate (KR-20 = 0.64 at pretest), and several items showed weak discrimination. Third, the posttest was administered immediately after the program and therefore measured immediate knowledge outcomes, not retention. Fourth, preparedness behavior and tsunami-specific knowledge were not measured separately. Fifth, the study was conducted at a single school with 40 students, and the grade-level subgroups were very small, so the results cannot be generalized. Future research should use a quasi-experimental design with a comparison group, parallel test forms, a delayed posttest to assess retention, and behavioral measures, such as an unannounced drill assessing siren recognition, action sequences, evacuation time, and route choice.

CONCLUSION

This study found that elementary school students' earthquake-related knowledge, including general disaster mitigation knowledge, increased immediately after participating in the Knowledge Meets Readiness (KMR) program, with a statistically significant improvement in understanding the causes of earthquakes. Exploratory analyses did not show statistically significant differences in gains by grade level or gender. Tsunami-specific knowledge and preparedness behavior were not measured separately.

The novelty of this study lies in integrating a functional earthquake–tsunami early warning system into a school-level disaster education program and evaluating its outcomes at the item level. The results indicate that such integration is feasible in an elementary school setting.

Because the evidence is limited to an immediate knowledge outcome from a single school without a control group, the effectiveness and scalability of KMR should be regarded as hypotheses for future research. Further studies should use a comparison group, a delayed posttest to assess retention, and unannounced drills to assess preparedness behavior.

Acknowledgments

The authors thank SDN 1 Pasauran, Cinangka District, Serang Regency, for its participation in this study. The KMR program was implemented through a collaboration between the Geology Study Program, Faculty of Mathematics and Natural Sciences, Universitas Indonesia, and PT. TOA Indonesia. Universitas Indonesia was responsible for the development and implementation of the disaster education program, while PT. TOA Indonesia supported the implementation of the early warning system used during the evacuation simulation. This program also funded by Universitas Indonesia with the contract number: PKS-059/UN2.PPM/HKP.05.01/2026.

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Funding
This research was funded by Universitas Indonesia under contract number PKS-059/UN2.PPM/HKP.05.01/2026. PT. TOA Indonesia also provided additional in-kind support through the provision and installation of an Early Warning System (EWS) at the beneficiary school.

Author Contributions
Twin H. W. Kristyanto: Data curation, Formal analysis, Investigation, Methodology, Supervision, Visualization, Writing, original draft, Educational material development; Isnaini Rahmawati: Conceptualization, Methodology, Formal analysis, Development of pre-test and post-test questions; Lupir F. Andika: Methodology (evacuation route map design), Visualization, Writing, review & editing; Olyvia N. Suryaningtyas: Methodology (evacuation route map design), Visualization, Writing, review & editing; Enjel T. Rongko': Investigation, Resources (learning materials), Formal analysis, Writing, original draft; Fendi La'ia: Formal analysis, EWS evacuation route mapping, Educational presentation design; Najmalika N. Amalia: Investigation, Field surveys, EWS evacuation route mapping; Junifa B. S. Andoyo: Investigation, Resources (learning materials), Formal analysis, Writing, original draft.

Conflict of Interest
The authors declare no conflict of interest.

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