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Development of MITEDA (Mitigation of Earthquake Damage) Media for Wave Physics Using a STEM Approach to Enhance Students' Computational Thinking Skills

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ABSTRACT

Purpose of the study: The aim of this study is to develop and evaluate the effectiveness of a learning media called MITEDA (Mitigation of Earthquake Damage), which is based on the STEM approach and computational thinking, to support the teaching of wave physics. The study focuses on both the development process of the media and its impact on improving students' computational thinking skills through contextual problem-solving using earthquake simulation and sensor-based data.

Methodology: The research method used is Research and Development (R&D) with the ADDIE (Analysis, Design, Development, Implementation, and Evaluation) model. Tools used include Arduino Uno, SW-420 vibration sensor, LCD 16x2, and a buzzer. Software includes Arduino IDE and Proteus. Data collection used expert validation sheets, student questionnaires, observations, and computational thinking tests.

Main Findings: The MITEDA learning media, comprising a digital seismograph kit and instructional module, was rated "highly feasible" by experts (Aiken's $V \geq 0.80$) and received positive student feedback for usability and engagement. Statistical analysis showed a significant improvement in computational thinking skills for the experimental group (N-Gain = 0.84) compared to the control group (N-Gain = 0.56), $t(69) = 8.875$, $p < 0.001$, $d = 2.716$, with the highest gains in abstraction and consistent high-level algorithmic performance.

Novelty/Originality of this study: This study presents an innovative learning media, MITEDA, integrating STEM and computational thinking through earthquake simulation using Arduino-based sensors. It advances wave physics learning by providing real-time vibration data and contextual problem-solving, enhancing students' analytical skills.

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1. INTRODUCTION

Education in Indonesia has undergone significant transformation through the implementation of the Merdeka Curriculum, which emphasizes learning flexibility and encourages schools and teachers to innovate in their teaching methods. Its primary goal is to facilitate students' holistic development cognitively, affectively, and psychomotorically while preparing them for the challenges of the 21st century [1]. The curriculum also focuses on developing core competencies such as critical thinking, creativity, collaboration, and communication.

Despite these reforms, science education, particularly physics, still faces challenges. Physics is often perceived as abstract and difficult, with topics such as wave phenomena taught in a theoretical manner, disconnected from real world applications. This disconnect reduces student motivation and comprehension [2]. One effective way to make wave physics more meaningful is by linking it to real-world phenomena like earthquakes. Seismic waves elastic waves propagating through the Earth due to tectonic activity consist of body waves (P and S) and surface waves (Rayleigh and Love), the latter often causing the most damage [3], [4]. In physics education, concepts such as amplitude, frequency, and propagation speed can be taught through the analysis of seismic data, fostering both conceptual understanding and disaster awareness [5]. This is particularly relevant for Indonesia, located on the Pacific Ring of Fire, where over 5,000 earthquakes occur annually [6].

The STEM (Science, Technology, Engineering, and Mathematics) approach integrates theory with real world application, encouraging problem solving through experimentation, design projects, and innovation [7]-[11]. In wave physics, STEM enables students to understand seismic phenomena and explore engineering solutions for earthquake mitigation. Technological advances further support this approach. Modern learning increasingly involves data exploration, modeling, and simulation. For example, digital earthquake simulations allow students to analyze seismic data, observe wave propagation, and assess its impact on structures, requiring them to apply key computational thinking (CT) skills: problem decomposition, pattern recognition, abstraction, and algorithm design [12], [13]. Integrating STEM and CT equips students not only with scientific literacy but also with 21st-century problem solving and design skills [14]-[17].

Several learning media such as PhET simulations, Arduino based experiments, and game based science environments have attempted to integrate STEM and CT [18]. However, most focus on a single aspect (e.g., visualization or programming) without embedding CT into a disaster mitigation context. Prior studies on Arduino based seismographs demonstrate potential for hands on wave measurement and real time data analysis, yet they rarely integrate complete instructional design for wave physics or combine with earthquake mitigation strategies. Similarly, wave pedagogy research has highlighted the benefits of connecting theory to natural phenomena, but implementations are often limited to static demonstrations rather than interactive, sensor-based learning.

These gaps indicate the need for educational media that is interactive, contextually relevant, and fully integrates STEM and CT within the framework of earthquake disaster mitigation. The development of MITEDA (Mitigation of Earthquake Damage) addresses this need by combining Arduino based seismic measurement tools, computational thinking pedagogy, and STEM based learning to make wave physics both engaging and applicable to real world problems.

2. RESEARCH METHOD

This study employed a Research and Development (R&D) approach, focusing on the creation of instructional media named MITEDA (Mitigation of Earthquake Damage) for teaching wave physics. The media integrates computational thinking (CT) and the STEM approach (Science, Technology, Engineering, and Mathematics). The product consisted of two main components: a hardware component in the form of a seismograph kit and a software component in the form of a graphical user interface (GUI) designed for teaching wave concepts. The development model combined the ADDIE instructional design model (Analysis, Design, Development, Implementation, Evaluation) [19] with the waterfall development model [20], ensuring a structured process for both instructional and technical development.

The development procedure followed the five stages of the ADDIE model, aligned with the systematic sequence of the waterfall model. The Analysis stage corresponded to the Communication stage in the waterfall model, focusing on identifying learning needs, student characteristics, and curriculum alignment. The Design stage was aligned with Planning, involving the creation of learning objectives, content outlines, media specifications, and interface prototypes. The Development stage matched the Modeling and Construction stages, in which the seismograph kit was produced, the GUI was programmed, and supporting learning materials were designed. The Implementation stage corresponded to Deployment, when the media was used in classroom learning sessions. Finally, the Evaluation stage involved both formative and summative evaluations of the media's feasibility and effectiveness.

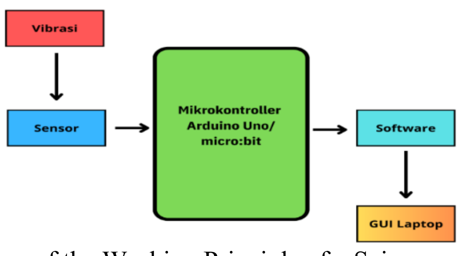

Figure 1. Block Diagram of the Working Principle of a Seismograph with GUI Software

The participants were Grade XI students (aged 16–17) from Senior high school 2 Bengkulu Selatan. The study involved two groups: the experimental class, which received instruction using MITEDA media, and the control class, which received instruction using conventional teaching methods. The implementation was conducted over three consecutive 90-minute lessons within the wave physics unit. In Lesson 1, students were introduced to wave concepts, given an overview of seismic waves, and oriented to the MITEDA hardware and software. Lesson 2 involved hands-on experiments using the seismograph kit, data collection via the GUI, and guided computational thinking exercises focusing on problem decomposition, pattern recognition, abstraction, and algorithm design. Lesson 3 consisted of group projects in which students designed earthquake-resistant structures using data from MITEDA simulations, followed by class discussion and reflection. The media was fully integrated into the existing curriculum and delivered by the physics teacher with assistance from the researcher.

The main instrument for measuring computational thinking skills was a test covering four indicators: problem decomposition, pattern recognition, abstraction, and algorithmic thinking. The assessment rubric was adapted from the University of Delaware Computational Thinking Rubric, with a score range from 0 (no evidence) to 4 (high proficiency). The scoring guidelines are shown in Table 1.

Table 1. Scoring Guidelines for the Computational Thinking Skills Test

Assessment Aspect	Assessment Criteria	Score
Problem Decomposition	Student provides no answer	0
	Student is able to break down the problem, but the breakdown lacks detail, overlaps, and is inefficient	1
	Student is able to break down the problem efficiently but not in detail	2
	Student is able to break down the problem in detail but not effectively	3
	Student is able to break down the problem in a detailed and effective manner	4
Pattern Recognition	Student provides no answer	0
	Student identifies similar or different patterns from those previously learned but does not apply them	1
	Student identifies similar or different patterns from those previously learned but applies them inappropriately (e.g., ambiguously)	2
	Student identifies similar or different patterns from those previously learned and applies them appropriately but not accurately	3
	Student identifies similar or different patterns from those previously learned and applies them appropriately and accurately	4
Abstraction	Student provides no answer	0
	Student removes unimportant elements from the problem, but only a few important elements are used and inefficiently	1
	Student removes unimportant elements from the problem, but the important elements are not fully and efficiently explained	2
	Student removes unimportant elements from the problem, and the important elements are fully explained but inefficiently	3
	Student removes unimportant elements from the problem, and the important elements are fully and efficiently explained	4
Algorithmic Thinking	Student provides no answer	0
	Student is able to solve the problem, but the steps are not sequential and do not follow mathematical conventions	1
	Student is able to solve the problem with sequential steps, but they do not follow mathematical conventions	2
	Student is able to solve the problem with steps that are not sequential but follow mathematical conventions	3
	Student is able to solve the problem with sequential steps that follow mathematical conventions	4

Other instruments included expert validation sheets for media and material evaluation, and a student response questionnaire to assess usability and engagement after using the media. Data collection involved administering pretests and posttests to measure computational thinking skills before and after the intervention, gathering expert validation scores for both the hardware and software, and distributing student response surveys at the end of the learning sessions.

Data analysis consisted of both descriptive and inferential statistics. The normality test was performed using the Shapiro-Wilk test, chosen over the Kolmogorov-Smirnov test because the sample size in each group was less than 50, making it more powerful for small samples. Data were considered normally distributed if the p-value was greater than 0.05. Homogeneity of variances was verified using Levene's test to ensure that the assumptions for parametric testing were met.

The effectiveness of the STEM-based intervention was analyzed using the Normalized Gain (N-Gain) score, which measured learning improvement according to the following formula:

$$N - Gain = \frac{Skor\ Postest - Pretest}{Skor\ Ideal - Skor\ Pretest}$$

The classification categories for N-Gain scores are shown in Table 2.

Table 2. N-Gain Score Classification Categories

Variable	Category	Persentage (%)
x	Bad	8.6
y	Sufficient	12.4
z	Good	15.3

Table 3. Category of N-Gain Score Effectiveness Interpretation

Variable	Category	Persentage (%)
x	Bad	8.6
y	Sufficient	12.4
z	Good	15.3

$$N - Gain = \frac{Skor\ Postest - Pretest}{Skor\ Ideal - Skor\ Pretest}$$

An Independent Samples t-Test was used to compare posttest means between the experimental and control groups. This test was selected instead of ANCOVA because the study aimed to directly compare final learning outcomes after confirming that both groups had statistically equivalent pretest scores. The t-Test was deemed appropriate given the normality and homogeneity results, as well as the study's quasi-experimental design. A significance value (sig.) of less than 0.05 indicated a statistically significant difference between the two groups.

The integration of ADDIE and waterfall models ensured a systematic process for both instructional and technical development. The ADDIE model provided a pedagogical framework for instructional design, while the waterfall model supported the sequential development of the software and hardware components. This combination resulted in a meaningful and practical learning tool designed to enhance students' understanding of wave concepts through computational thinking and contextual disaster-related content.

3. RESULTS AND DISCUSSION

Testing the Assumptions of Analysis

Normality Test

In the normality test, the Shapiro-Wilk method was employed with the assistance of the R program in R Studio at a significance level of 0.05. If the significance value (sig) is greater than 0.05 (sig > 0.05), the data are considered to be normally distributed. The results of the normality test are presented in the following table 4.

Table 4. Normality Test Results

Variable	Category	Persentage (%)
x	Bad	8.6
y	Sufficient	12.4
z	Good	15.3

he normality test was conducted using the Shapiro-Wilk method, as the sample size in this study was fewer than 50 participants. The results, as presented in the previous table, indicate that the significance values (Sig) for both the experimental and control groups exceed 0.05. Thus, it can be concluded that the data in this study are normally distributed.

Homogeneity Test

The homogeneity test is used to analyze whether two variables have equal variances. If both variables have the same or homogeneous variance, a comparison (comparative analysis) can be conducted. However, if the variances of the two variables differ, then the comparison cannot be performed. The results of the homogeneity test are presented in the following table 5.

Table 5. Homogeneity Test Results

Student Learning Outcomes	Persentage (%)	Category
Pretest vs Posttest Experiment	0.538	Homogeneous
Pretest vs Posttest Control	0.960	Homogeneous

N-Gain Effectiveness Test Results

Based on the results of the homogeneity test presented in the table, it is known that the significance value for the variance of student learning outcomes in the Pretest vs Posttest Experiment group is 0.538, and the significance value for the Pretest vs Posttest Control group is 0.960. Since these significance values are greater than 0.05 (0.701 > 0.05), it can be concluded that the variance of the posttest learning outcomes for the experimental and control classes is homogeneous.

Table 6. Comparison Results of N-Gain Scores

Statistic	Experimental Class	Std. Error	Control Class	Std. Error
Mean	83.3333	3.29232	60.8333	2.58432
5% Trimmed Mean	83.3333	–	60.8333	–
Median	85.0000	–	60.0000	–
Variance	58.3333	–	4.1667	–
Standard Deviation	7.6376	–	2.0412	–
Minimum	75.0000	–	60.0000	–
Maximum	90.0000	–	65.0000	–
Range	15.0000	–	5.0000	–
Interquartile Range	7.5000	–	0.0000	–
Skewness	-0.3818	0.564	1.7889	0.524
Kurtosis	1.5000	1.091	4.2000	1.014

Based on the data presented in the table above, the average N-Gain score of students in the experimental class using the STEM-based learning model reached 83.33, which falls into the “moderately effective” category of N-Gain effectiveness. Meanwhile, the average N-Gain score of the control class using conventional learning was only 60.83, categorized as “ineffective.” These findings indicate that physics learning on wave material using the STEM-based approach is more effective in enhancing students’ computational thinking skills compared to conventional learning models.

Hypothesis Test Results (t-test)

Based on the results of the normality and homogeneity tests, it was found that the data were normally distributed and had homogeneous variances. Therefore, an analysis of the difference in posttest scores between the experimental and control classes was conducted using the Independent Samples t-Test. This test aims to determine the significance of the difference in physics learning outcomes on wave material between the experimental class, which implemented the STEM-based learning model, and the control class, which applied the conventional learning model. The analysis was carried out using the R software in R Studio. The results of the Independent Samples t-Test are presented as follows:

```
Two Sample t-test
data: postes_kontrol and postes_eksperimen
t = -7.4246, df = 4, p-value = 0.001757
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
-19.235315 -8.764685
sample estimates:
mean of x mean of y
70.66667 84.66667
```

Figure 2. R Program Output in R Studio

The analysis was conducted using the R software through RStudio. Based on the results, the following statistical values were obtained: t-value (t-calculated) = -7.4246, degrees of freedom (df) = 4, and p-value = 0.001757. The mean posttest score for the control class was 70.67, while the experimental class scored 84.67. The 95% confidence interval for the mean difference ranged from -19.24 to -8.76.

Since the p-value is less than 0.05, the null hypothesis (Ho) is rejected and the alternative hypothesis (Ha) is accepted. This indicates that there is a significant difference between the posttest scores of students in the experimental class and those in the control class. Therefore, it can be concluded that the STEM-based learning model has a significant effect on improving student learning outcomes in wave material compared to the conventional learning model [21]-[23].

Analysis of Each Indicator of Computational Thinking Skills

Decomposition

The analysis of computational thinking skills based on the problem decomposition indicator was conducted by comparing students' pretest and posttest results. The data were analyzed using statistical tests with the assistance of R Studio, and the results are presented as follows:

```
Indicator: Problem Decomposition_Pre
Pre-test Mean: 12
Post-test Mean: 19.2
p-value: 3.553944e-06
Conclusion: A significant improvement is
observed.
```

Figure 3. Statistical Test Results of Problem Decomposition with the Assistance of R Studio

The very small p-value (well below 0.05) indicates that there is a statistically significant difference between the pretest and posttest results for this indicator. This means that a significant improvement occurred in students' ability to decompose problems into the essential data required to solve mechanical wave problems. This improvement reflects that the learning intervention using the MITEDA media and the STEM approach based on Computational Thinking had a positive impact on students' decomposition skills [24], [25].

Pattern Recognition

Based on data analysis using R Studio, the pretest mean score was found to be 10.8, and the posttest mean score was 21 for the pattern recognition indicator. The statistical test yielded a p-value of 8.84623e-07, which is much smaller than the significance threshold of 0.05. This provides strong evidence that there was a significant improvement in students' ability to recognize wave patterns after the learning intervention using MITEDA media based on the STEM approach.

```
Indicator: Problem Decomposition_Pre
Pre-test Mean: 12
Post-test Mean: 19.2
p-value: 3.553944e-06
Conclusion: A significant improvement has been
observed.
```

Figure 4. Statistical Test Results of Problem Decomposition with the Assistance of R Studio

Qualitatively, this improvement is clearly evident through the changes in the way students think and present their answers. In the early stages of learning (pretest), students only made simple observations about physical patterns, such as the up-and-down motion of a string and the appearance of crests and troughs, without providing further analysis or understanding. The patterns mentioned were not linked to physical concepts and appeared as mere visual observations without scientific interpretation [26], [27]. This is evident in Question 1, where students only mentioned that wavelength is related to time, without explaining how frequency still affects wave speed.

Abstraction

The results of the quantitative analysis using R Studio show a significant improvement in students' computational thinking skills in the abstraction indicator. The pretest mean score was 10.4, while the posttest mean score increased to 21.2. The statistical test yielded a p-value of 2.50579e-05, which is significantly smaller than the 0.05 threshold. This indicates that learning with MITEDA media based on the STEM approach has a positive impact on improving students' ability to perform abstraction.

```
ndicator: Abstraction_Pre
Pre-test Mean: 10.4
Post-test Mean: 21.2
p-value: 2.50579e-05
Conclusion: A significant improvement is
observed.
```

Figure 5. Statistical Test Results of Problem Abstraction with the Assistance of R Studio

Qualitatively, this improvement is evident in the way students filter and process information within the context of wave phenomena. At the early stages of learning (pretest), students tended to mention various examples of vibrations (string, water, sound) randomly without distinguishing their relevance to the problem. They were unable to separate essential information from supplementary details, resulting in answers that were descriptive and broad [28]-[30]. For example, in Question 1 about the relationship between wavelength and speed, many students simply mentioned the terms wavelength and frequency without connecting them in a clear physical equation.

Algorithm Design

The quantitative analysis conducted using R Studio shows a significant improvement in students' algorithmic thinking skills. The pretest mean score was 10.8, while the posttest mean score increased to 23.8. A p-value of 2.092505e-06 indicates that this improvement is highly significant statistically, far below the 0.05 threshold. Therefore, it can be concluded that the learning intervention using MITEDA media and the STEM approach successfully enhanced students' ability to formulate problem-solving steps algorithmically.

```
Indicator: Algorithmic_Pre
Pre-test Mean: 10.8
Post-test Mean: 23.8
p-value: 2.092505e-06
Conclusion: A significant improvement is
observed.
```

Figure 6. Statistical Test Results of Problem Abstraction with the Assistance of R Studio

With the assistance of R Studio, the improvement is qualitatively evident in the changes in students' thinking patterns when organizing experimental steps. In the early stages (pretest), students only followed general instructions without organizing a logical sequence of work steps. They relied more on a trial-and-error approach and were not yet accustomed to thinking systematically when solving technical problems. For example, in Question 5 regarding evacuation response based on Δt, students were unable to determine the logical and sequential steps required to calculate Δt or select the appropriate sensor for evacuation, merely recording data without further analysis. After obtaining the data from the students' posttest responses, an analysis was conducted to determine the achievement of the Learning Outcome Criteria (KKTP). According to the school's guidelines, the KKTP score for class X is set at 65. This analysis aims to evaluate the effectiveness of using the MITEDA-based learning module in improving students' computational thinking skills.

The posttest score data that was obtained was then processed using R software. The results of this data processing are presented in the form of bar charts and pie charts, as shown in the figure 7.

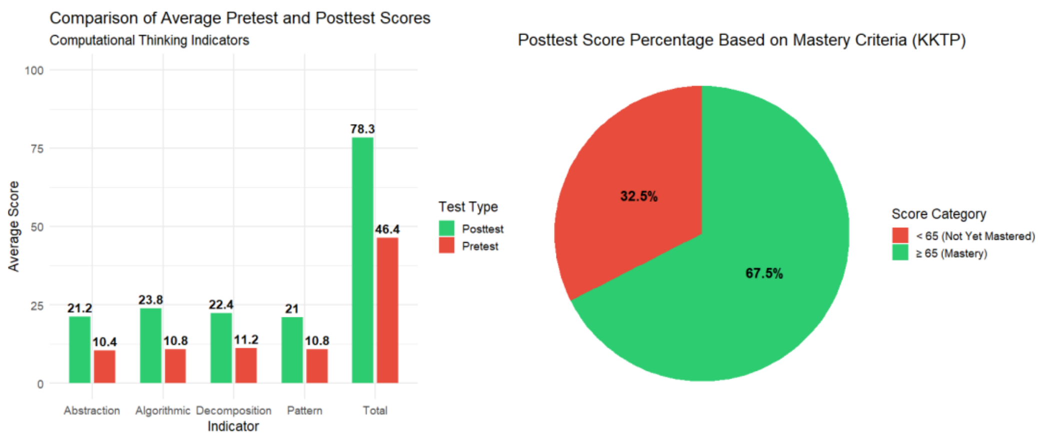

Figure 7. Pretest and posttest results for each indicator of computational thinking skills

The data indicate that students' posttest scores ranged from 43.75 to 98.75. Out of 36 students, 25 (67.5%) achieved scores equal to or above the Minimum Mastery Criteria threshold (≥ 65), while 11 students (32.5%) scored below the threshold (< 65). This finding demonstrates that the majority of students successfully met the minimum competency standards set by the school.

These results reinforce the conclusion that learning using the MITEDA media based on the STEM approach contributes positively to the enhancement of computational thinking skills. This is evident from the comparison of pretest and posttest average scores across all indicators—abstraction (increased from 10.4 to 21.2), algorithmic thinking (10.8 to 23.8), decomposition (11.2 to 22.4), and pattern recognition (10.8 to 21). The overall average score of students improved significantly from 46.4 on the pretest to 78.3 on the posttest.

This achievement is also supported by statistical tests, which revealed significant improvements across all indicators, as well as qualitative analysis showing a shift in students' thinking patterns toward a more systematic, logical, and scientific approach [31]-[35]. Therefore, it can be concluded that the instructional intervention using MITEDA is effective in comprehensively enhancing students' computational thinking competencies.

4. CONCLUSION

This study aimed to assess the effectiveness of using the MITEDA (Mitigation of Earthquake Damage) media based on a STEM approach to enhance students' computational thinking skills in wave physics learning. The research findings confirm that the integration of the MITEDA media significantly improved students' problem-solving and computational thinking abilities, particularly in the areas of decomposition, pattern recognition, abstraction, and algorithmic thinking. The experimental group that used the STEM-based learning model showed a notable increase in their posttest scores, with a mean N-Gain score of 83.33, categorized as "moderately effective," while the control group using conventional methods achieved a score of 60.83, categorized as "ineffective." The normality and homogeneity tests indicated that the data were normally distributed and had homogeneous variances, ensuring the validity of the subsequent statistical analyses. The hypothesis test (Independent Samples t-Test) revealed a significant difference between the experimental and control groups, with a t-value of -7.4246 and a p-value of 0.001757, supporting the effectiveness of the STEM-based learning model. Additionally, each indicator of computational thinking skills—problem decomposition, pattern recognition, abstraction, and algorithm design—demonstrated significant improvements post-intervention.

The findings highlight the potential of MITEDA media as an effective learning tool for improving computational thinking in physics education. It is evident that the STEM-based approach provides a more engaging and interactive learning environment that fosters deeper understanding and enhances students' problem-solving abilities. Based on these promising results, several future research directions are recommended, ranging from short-term to long-term initiatives. In the short term, usability testing in diverse classroom settings could be conducted to refine MITEDA's features and improve its user interface, while localization efforts such as adapting the content to regional languages and incorporating local earthquake case studies could enhance student engagement. Additionally, developing offline versions of MITEDA would improve accessibility for schools with limited internet connectivity, ensuring equitable access to STEM based learning tools. In the long term, research could explore the integration of MITEDA into other science subjects and its adaptation for various educational contexts, including primary and vocational education, as well as investigate its sustained impact on students' academic performance and critical thinking skills across different age groups. Furthermore, scaling MITEDA for national implementation and embedding its use into teacher training programs would help sustain its benefits and promote widespread adoption in the education system.

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