

DEVELOPMENT A SCIENCE E-BOOK BASED-DEEP LEARNING USING SCAFFOLDING TECHNIQUES TO IMPROVE STUDENT'S EXPLANATION SKILL AND INDEPENDENT LEARNING

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ABSTRAK

This study aimed to develop a science e-book integrating discovery learning, deep learning principles, and scaffolding techniques to improve students' explanation skills and learning independence. The study employed a Four-D (4D) development model consisting of Define, Design, Develop, and Disseminate stages. The product was validated by two experts in science content and educational media. The effectiveness test involved 62 eighth-grade students from SMP Negeri 6 Klaten, Indonesia, divided into an experimental class and a control class. The intervention was conducted over three learning sessions on vibrations and waves. Data were collected using validation sheets, practicality and readability questionnaires, a Claim–Evidence–Reasoning (CER)-based explanation skills test, and a learning independence questionnaire. Data were analyzed using descriptive statistics, MANOVA, N-Gain, and effect size analyses. The results showed that the developed e-book was highly feasible and practical. MANOVA results indicated significant differences in explanation skills and learning independence between the experimental and control groups ($p < 0.05$). N-Gain and effect size analyses further showed moderate improvements in both variables. Therefore, the developed e-book is feasible, practical, and effective for supporting science learning.

Keywords: e-book; deep learning; scaffolding; explanation skills; learning independence

INTRODUCTION

Twenty-first-century science education emphasizes the development of higher-order thinking skills, scientific literacy, communication skills, and self-regulated learning. Students are expected not only to acquire scientific knowledge but also to apply concepts, solve problems, and explain scientific phenomena using evidence-based reasoning (Council, 2012). These competencies are increasingly important in preparing students to face complex challenges and rapid developments in science and technology.

One important competency in science learning is explanation skill, which refers to students' ability to construct scientific explanations by integrating claims, evidence, and reasoning (McNeill

& Krajcik, 2008). Scientific explanation enables students to connect observations with scientific concepts and justify conclusions using valid evidence. Previous studies have shown that students frequently experience difficulties in developing complete scientific explanations, particularly when linking evidence to scientific reasoning (Berland & McNeill, 2010). As a result, students often provide answers that lack scientific justification and conceptual coherence.

In addition to explanation skills, learning independence has become an essential goal of contemporary education. Learning independence allows students to take responsibility for their learning, monitor their progress, and evaluate their

understanding. According to (Zimmerman, 2008), self-regulated learners actively manage cognitive, motivational, and behavioral aspects of learning. However, many students still demonstrate low levels of self-regulation, characterized by excessive dependence on teachers and limited initiative in learning activities (Cobo-Rendón et al., 2020).

Various instructional innovations have been developed to address these challenges. The integration of digital technology into education has led to the widespread use of interactive e-books as learning resources. Interactive e-books can enhance student engagement, conceptual understanding, and learning outcomes by incorporating multimedia content, simulations, and interactive activities (Lin et al., 2017). Recent studies have also highlighted the effectiveness of digital learning environments in promoting meaningful learning and student autonomy (Cheng & Tsai, 2019).

Furthermore, the Claim–Evidence–Reasoning (CER) framework has been widely recognized as an effective approach for improving students’ scientific explanation skills. CER helps learners construct evidence-based arguments, connect scientific concepts with observations, and communicate scientific ideas more effectively (Berland & McNeill, 2010). Previous studies have reported that CER-oriented instruction can significantly improve students’ ability to develop scientific explanations and arguments (Fitriani et al., 2022).

The topic of vibrations and waves was selected because it is one of the most conceptually challenging topics in junior secondary science. Students often experience difficulties in visualizing wave propagation, understanding relationships

among wave variables, and applying concepts to everyday phenomena. These difficulties may hinder conceptual understanding and scientific reasoning if appropriate learning support is not provided (Fosnot, 2013).

Discovery learning is an instructional model that encourages students to actively construct knowledge through exploration, investigation, and problem-solving activities. Research has shown that discovery learning can improve conceptual understanding and critical thinking when students are actively engaged in the learning process (Alfieri et al., 2011). However, students may struggle to discover concepts independently when sufficient guidance is unavailable (Hmelo-Silver et al., 2019). Therefore, scaffolding techniques are needed to provide structured support that gradually decreases as students develop greater competence and independence (Van de Pol et al., 2024).

In addition, the deep learning approach emphasizes meaningful understanding through critical analysis, reflection, and knowledge transfer rather than surface memorization. Deep learning encourages students to connect new knowledge with prior experiences and apply concepts in different contexts (Fullan et al., 2018). Recent studies have further highlighted the potential of deep learning approaches in fostering higher-order thinking and meaningful learning outcomes in digital learning environments (Hwang & Chien, 2022).

Although previous studies have demonstrated the effectiveness of interactive e-books, discovery learning, scaffolding techniques, CER-based instruction, and deep learning approaches separately, limited studies have integrated

these components into a single digital learning resource (Sung et al., 2022). More specifically, few studies have examined the effectiveness of a discovery learning-based science e-book that incorporates deep learning principles and scaffolding techniques to simultaneously improve students' explanation skills and learning independence on the topic of vibrations and waves. This gap highlights the need for innovative instructional materials that support both scientific explanation and self-directed learning.

Therefore, this study aimed to develop a science e-book based on discovery learning integrated with deep learning principles and scaffolding techniques. The study further examined the feasibility, practicality, and effectiveness of the developed e-book in improving students' explanation skills and learning independence.

METHOD

Delopment (R&D) project aimed at producing a science e-book based on discovery learning with a deep learning approach using scaffolding techniques on the topic of vibrations and waves. The development model used is the 4D (Four-D Model) D) Model developed by (Thiagarajan et al., 1974), which consists of four stages : define, design, develop, and disseminate.

The define stage was conducted to analyze learning needs, student characteristics, and the subject matter. The design stage involved designing the e-book in accordance with the discovery learning syntax, the deep learning approach, and the scaffolding technique. The develop stage included expert validation and product testing to determine the e-book's feasibility. The disseminate stage was

conducted on a limited basis within the research environment.

The study was conducted at SMP Negeri 6 Klaten during the second semester of the 2025/2026 academic year. The study subjects consisted of two classes: Class VIII A as the experimental class and Class VIII B as the control class, each comprising 31 students. The effectiveness test utilized a quasi experimental design with a pretest-posttest control group design.

Tabel 1 *pretest-posttest control group design.*

Group	Pretest	Posttest	Treatment
Experimental Class	O ₁	O ₂	X ₁
Control Class	O ₃	O ₄	X ₂

The developed e-book integrated discovery learning activities, deep learning principles, and scaffolding techniques. The e-book contained learning objectives, contextual phenomena, interactive illustrations, PhET simulations, CER-based activities, reflective questions, formative assessments, and learning summaries designed to support students' conceptual understanding and learning independence.

Prior to implementation, the science teacher participated in a briefing session conducted by the researcher. The session introduced the objectives of the study, the structure of the developed e-book, discovery learning procedures, scaffolding strategies, and the use of learning activities embedded in the e-book. This briefing was intended to ensure that the intervention was implemented consistently according to the research design.

The intervention was conducted over three instructional sessions, with each session lasting 80 minutes. During the first

session, students explored vibration concepts through contextual phenomena presented in the e-book. Students identified problems and formulated initial ideas through guiding questions. Scaffolding was provided in the form of prompts, concept hints, and structured questions to support concept discovery (Backfisch et al., 2021).

During the second session, students investigated vibration and wave phenomena using interactive illustrations and PhET simulations integrated into the e-book. Students collected information, analyzed relationships among variables, and completed Claim–Evidence–Reasoning (CER)-based activities. Additional scaffolding was provided through procedural guidance, worked examples, and feedback to facilitate conceptual understanding.

During the third session, students constructed scientific explanations based on the CER framework and reflected on their learning experiences. Students completed formative assessment activities and answered reflective questions. At this stage, scaffolding support was gradually reduced to encourage greater learning independence.

The e-book incorporated several scaffolding features, including guiding questions, concept hints, structured learning tasks, worked examples, feedback sections, reflective questions, and CER-based activities. These features were designed to provide temporary support and gradually transfer learning responsibility to students as their understanding developed.

Data collection was conducted through a Claim–Evidence–Reasoning (CER)-based explanatory skills test and a student learning independence questionnaire. The research instruments

were validated by experts and tested for reliability before being used in the study. Data were analyzed using the N-gain test to determine improvements in student ability. Furthermore, the effect of e-book use on explanatory skills and learning autonomy was analyzed using MANOVA (Multivariate Analysis of Variance). Prior to conducting the MANOVA test, prerequisite tests were performed, including tests for normality, homogeneity of variances, homogeneity of covariance matrices, linearity, multicollinearity, absence of multivariate outliers, data independence, equality of sample sizes, and measurement of the dependent variable on an interval or ratio scale.

Additionally, an effect size test was conducted to determine the magnitude of the influence of e-book use on the research variables. The interpretation of effect size followed Cohen's criteria, namely small, moderate, and large categories.

RESULTS AND DISCUSSION

The deep learning-based e-book product utilizes scaffolding techniques, which have been validated by experts, and was further developed through pilot testing to assess its practicality, readability, and effectiveness in learning. The pilot testing was conducted in two phases: a limited pilot test and a field pilot test. Subsequently, an effectiveness test of the product was conducted.

1. Limited trial

After the e-book was developed through a revision process, a pilot test had to be conducted before field testing. The pilot test was conducted with 2 science teachers and 30 eighth-grade students at SMPN 6 Klaten to assess their responses regarding the e-book's practicality and readability.

2. Field test results

A field experiment was carried out to assess the efficacy of the created product. The research utilized a nonequivalent pretest-posttest control group format featuring two distinct treatment groups. The experimental class used a deep learning-based science e-book incorporating scaffolding techniques, while the control class used a science textbook from the Ministry of Education and Culture that applied the discovery learning model. Both classes participated in three learning sessions with equivalent content and duration.

A pretest was administered to both the control and experimental classes before instruction began to assess students' initial explanatory skills and learning autonomy. At the end of the instruction, a posttest was administered to both the control and experimental classes to assess improvements in students' explanatory skills and analysis learning autonomy. Data was conducted using an independent t-test to determine the difference in means between the control and experimental classes for each variable, namely students' explanatory skills and learning autonomy. Comparisons were made separately for posttest scores and N Gain scores. A prerequisite test was conducted before the t-test was performed. Data that did not meet the parametric assumptions were analyzed using the non parametric Mann-Whitney U test as an alternative.

3. Analysis of Product Effectiveness Testing

An analysis of effectiveness was performed to evaluate the impact of the Science E-Book. Before conducting the MANOVA test, the average scores of students were calculated to measure enhancements in learning outcomes and to

evaluate how the developed product affected students' skills by contrasting pre- and post-treatment results in both the experimental and control groups. The subsequent table illustrates the scores obtained by the students.

Table 2: Students' Average Scores

Variable	Test	Class	Student Scores
Explanation Skills	Pretest	Experiment	63,12
		Control	56,49
	Posttest	Experiment	80,53
		Control	72,19
Learning Independence	Pretest	Experiment	70,15
		Control	64,98
	Posttest	Experiment	83,00
		Control	76,21

The analysis of the product's effectiveness was based on the pretest posttest scores from the explanatory skills test and the student learning independence questionnaire. These scores were analyzed using MANOVA (Multivariate Analysis of Variance). Subsequently, a prerequisite test was conducted to ensure that the data met the requirements as stipulated; if the data did not meet the requirements, the MANOVA test could not proceed (Field, 2009). According to (Tabachnick & Fidell, 2019), the following is a description of the effectiveness test conducted:

a. MANOVA Prerequisite Test

Prerequisite tests were conducted to verify the assumptions required for the MANOVA test. These tests utilized pretest and posttest data on students' explanatory skills and learning autonomy. This analysis was performed by verifying the MANOVA assumptions as follows:

1) Assumption 1

The first assumption is that the variables consist of two or more variables on an interval or ratio scale. The independent variable in this study is a deep learning-based e-book using scaffolding techniques. In this study, the initial data for the explanatory skills variable is already on an interval scale, whereas the data on students' learning autonomy is still on an ordinal scale because the assessment instrument is a questionnaire. Therefore, the data on students' learning autonomy needs to be converted to an interval scale. The conversion process was performed using the Method of Successive Intervals (MSI) with the aid of Microsoft Excel. Consequently, the data on explanatory skills and students' learning autonomy are now in interval form, thus fulfilling the assumption.

2) Assumption 2

The second assumption is that the dependent variable must consist of two or more variables. The dependent variables in this study are students' explanatory skills and self-directed learning. Thus, this assumption is met.

3) Assumption 3

The third assumption is that there must be observer independence. This means there is no relationship between the observers in each class group used. This study uses an experimental class and a control class. Thus, assumption 3 is met.

4) Assumption 4

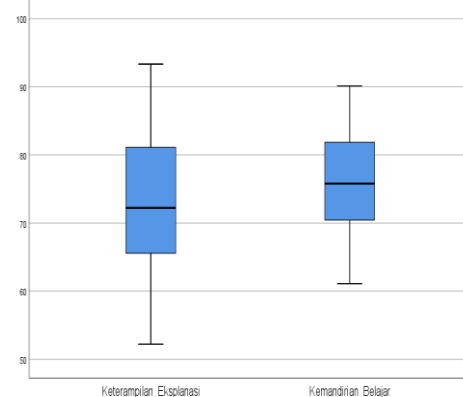
The fourth assumption is that there must be an adequate sample size, with a minimum of 25 samples. The samples used in this study were 31

students in the control class and 31 students in the experimental class. Therefore, assumption 4 is met.

5) Assumption 5

The fifth assumption is that there are no outliers in each variable group. The outlier test aims to determine whether there is data that deviates extremely, both in the independent and dependent variables in each group studied. The outlier test is conducted by determining the value limits that are categorized as outliers based on the data distribution.

Outliers can be identified using a boxplot by locating data points that fall outside the whiskers as extreme values (Hair et al., 2018). The results of the univariate outlier test in this study are presented in boxplots for the variables of explanatory skills and learning independence. The results of the univariate outlier test are shown in Figure 1 below:



Based on the boxplot results, there are no data points outside the whiskers for either variable, whether explanatory skills or learning independence. This indicates that no data were categorized as outliers for these two variables. The explanatory skills variable exhibits a relatively uniform distribution, with the median positioned centrally and no values that

significantly deviate from the overall dataset. Likewise, the distribution of the independent learning variable displays a fairly normal shape, without any outliers present. Thus, it can be concluded that Assumption 5 the absence of outliers has been

6) Assumption 6

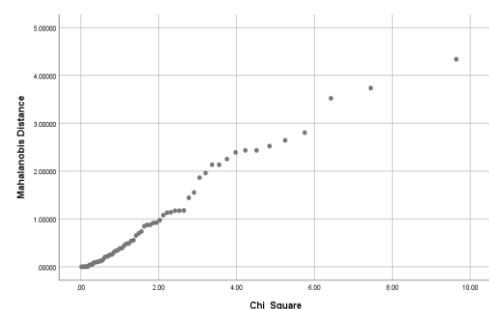
The sixth assumption is that the data being tested must be normally distributed. Univariate and multivariate normality tests were conducted to determine whether the obtained data are normally distributed. The univariate normality test was performed using the Shapiro-Wilk test because the sample size was less than 50 in each group. The data is considered normally distributed if the significance value (Sig.) is greater than 0.05 (Ghozali, 2018). The results of the normality test can be seen in Table 3 below. Table 3 Results of the Normality Test

Variabel	Tes	Kelas	Sig
Explanation Skills	Pretest	Experimental	0.156
		Control	0.256
	Posttest	Experimental	0.086
		Control	0.692
Learning Independence	Pretest	Experimental	0.121
		Control	0.980
	Posttest	Experimental	0.374
		Control	0.129

Based on the results of the Shapiro-Wilk test presented in the table, it is known that for the explanatory skills variable, both in the pretest and posttest in the experimental and control classes, all significance values are greater than

0.05. Specifically, the pretest significance value for the experimental class was 0.156, and for the control class, it was 0.256. In the posttest, the significance value for the experimental class was 0.086, and for the control class, it was 0.692. Furthermore, regarding the learning independence variable, the results of the normality test also showed that all significance values were above 0.05. In the pretest, the significance value for the experimental class was 0.121 and for the control class was 0.980. Meanwhile, in the posttest, the significance value for the experimental class was 0.374 and for the control class was 0.129. This indicates that the data on explanatory skills and learning independence in both classes and for both types of tests are normally distributed. Normality tests can also be performed using multivariate normality tests, which aim to identify data points that fall outside the normal range of Multivariate the available normality data. testing examines the results of a scatter plot of Mahalanobis distance versus the chi-square value. The results of the normality test are shown in Figure 2 below.

Figure 2 Scatter Plot Results of the Multivariate Normality Test



In Figure 2, it can be seen that the normality test results form a straight line for more than 50% of the Mahalanobis distance and Chi-Square plots, indicating that the data is multivariate normally distributed.

Next, a correlation analysis between the variables was conducted. In addition to showing that the data are multivariate normally distributed, the pattern of points on the scatter plot that tend to follow a diagonal line also indicates a linear relationship between the variables. This serves as the basis that the assumption of linearity in multivariate analysis has been met. Therefore, a correlation analysis between the variables is necessary to determine the strength and direction of the relationship between the explanatory skills and self-directed learning variables (Hair et al., 2019). The results of the correlation analysis are presented in Table 3 below.

Table 3 Correlation Analysis Results

Correlations		
		Chi_Square
Mahalanobis Distance	<i>Pearson Correlation</i>	0.988**
	<i>Sig. (2-tailed)</i>	0.000
	<i>N</i>	62
** Correlation is significant at the 0.01 level (2-tailed)		

Table 3 shows that there is a very strong correlation. In Figure 2, it can be seen that the normality test results form a straight line for more than 50% of the Mahalanobis distance and Chi-Square plots, indicating that the data is multivariate normally distributed. Between Mahalanobis distance and chi-square, with a Pearson correlation coefficient of 0.988 and supported by a significance

level (2-tailed) of 0.005; thus, the correlation is deemed significant. It can be inferred that the data conform to a normal distribution, and both the univariate and multivariate normality assumptions, along with Assumption 6, are satisfied.

7) Assumption 7

The seventh assumption aims to examine the linear relationship between each pair of variables. The basis for decision-making in the linearity test is the significance value of the deviation from linearity, with a significance level of $0.401 > 0.005$, indicating that there is a linear relationship between each pair of variables. The results of the linearity test are shown in Table 4 below.

Table 4 Results of the Linearity Test

		df	Sig.
Independent Learning*Explanatory Skills	<i>Combined</i>	30	0.288
	<i>Linearity</i>	1	0.032
	<i>deviation form linearity</i>	29	0.401

Based on Table 4, it is known that the significance value of the pretest and posttest data for students' explanatory skills and learning independence in the experimental and control classes, 0.401, is greater than 0.05, indicating that there is a linear relationship between the variable groups.

8) Assumption 8

The eighth assumption is the homogeneity test, which assumes that the variance and covariance matrices are homogeneous. The homogeneity test of the variance matrix was conducted using SPSS by examining Levene's Test of Equality of Error Variance in the "Based on Mean"

column. The results of the homogeneity of variance test can be seen in Table 5 below.

Table 5 Results of the Homogeneity of Variance Test

<i>Levene's Test Of Equality Of Error</i>				
Data	Levene Statistic	df1	df2	Sig.
Explanation Skill	3.322	1	60	0.073
Learning Independence	3.295	1	60	0.522

Based on Table 5, it is evident that the significance values for the explanatory skills and independent learning data in the experimental and control classes are greater than 0.05, indicating that the explanatory skills and independent learning data are univariate homogeneous. The covariance matrix homogeneity test was conducted using SPSS by examining Box's test of equality of covariance matrices (Box's M). The results of the covariance homogeneity test can be seen in Table 6 below.

Table 6 Results of the Covariance Homogeneity Test

Box's M	1.430
F	0.459
df1	3
df2	648000.000
Sig.	0.711

Based on Table 6, the significance value is 0.711. Therefore, it can be concluded that the data is homoscedastic.

9) Assumption 9

Assumption 9 is the multicollinearity test, with the assumption that there is no multicollinearity among the dependent variables. The results of the

multicollinearity test can be seen in Table 7 below: Table 7 Results of the Multicollinearity Test

Data	Collinearity Statistics	
	Tolerance	VIF
Keterampilan Eksplanasi	0.926	1.080
Kemandirian Belajar	0.926	1.080

Based on Table 7, the tolerance and Variance Inflation Factor (VIF) values for the data on students' explanatory skills and independent learning show that the tolerance values are greater than 0.10, while the VIF values are less than 10.00. Therefore, it can be concluded that there is no multicollinearity, and assumption 9 is met.

After all MANOVA prerequisite tests were met, the data proceeded to MANOVA analysis.

b. MANOVA Test

The MANOVA test aims to identify significant differences in each variable between the control and experimental classes. The results of the MANOVA test can be seen in the following hypothesis tests:

1) Hypothesis Test 1

Hypothesis 1 aims to determine whether there is a difference in pretest-posttest scores for explanatory skills and the student learning independence questionnaire between the control class and the experimental class. The hypothesis is as follows:

Ho: There is no difference in students' explanatory skills and learning independence questionnaire scores between the control and experimental classes.

H₁: There is a difference in students' explanatory skills and learning independence questionnaire scores between the control and experimental classes.

test can be seen in the following table 8 multivariate test output results.
Table 8 Multivariate Test Output

Within Subject	Effect	F	Sig.
Time* kelas	Hotelling's Trace	4.457	0.016

Based on Table 8, the sig. value of Hotelling's trace is $0.016 < 0.05$, which means H₁ is accepted and H₀ is rejected. Thus, it can be concluded that there is a significant difference in students' explanatory skills and learning independence between the control class and the experimental class.

2) Hypothesis Test 2

Hypothesis test 2 aims to determine whether there is a significant difference in each dependent variable between the experimental class and the control class. The hypotheses are as follows:

Explanation Skills

H₀: There is no difference in explanatory skills between the control class and the experimental class.

H₁: There is a difference in explanatory skills between the control class and the experimental.

Learning Independence

H₀: There is no difference in learning independence between the control class and the experimental class.

H₁: There is a difference in learning independence between the control class and the experimental class.

Source	Dependen variabel	Sig.
Class	Explanation Skills	0.024
	Independent Learning	0.022

Based on Table 9, the sig. value is <0.05 , which means H₁ is accepted and H₀ is rejected. Based on this, it can be concluded that there is a significant difference in students' explanatory skills and learning independence between the control class and the experimental class.

c. N-Gain Test

The N-Gain test aims to determine the increase in pretest posttest scores for students' explanatory skills and learning independence in the control and experimental classes. The results of the N-Gain test can be seen in Table 10 below:

Table 10 N-Gain Test Results

Variable	N-Gain Score	Category
Explanation Skills	0.43	Moderate
Learning Independence	0,41	Moderate

Based on Table 10, the N-Gain scores for explanatory skills and learning independence differ. The explanatory skills score in the experimental class was 0.43, falling into the moderate category, while the N-Gain score for student learning autonomy was 0.41, also falling into the moderate category. Based on the N-Gain test results, it can be concluded that the experimental class,

which used a deep learning-based science e-book employing scaffolding techniques, was proven to enhance students' learning autonomy.

d. Effect size Test

The effect size test aims to determine the extent of the impact of using e-books on students' explanatory skills and learning autonomy. The effect size test refers to the Cohen's *d* test. The results of the effect size test can be seen in Table 11 below.

Table 11 Effect Size Test Results

Variabel	Effect Size	Kategori
Explanatory skills	0,082	Moderate
Learning Independence	0,085	Moderate

Based on Table 11, a value of 0.082 was obtained for the explanatory skills variable and 0.085 for the learning independence variable. Both values fall into the moderate category, indicating a significant influence on the improvement of students' explanatory skills and learning independence. Therefore, it can be concluded that e books are effective in improving students' explanatory skills and learning independence.

The results of the study indicate that a deep learning-based science e-book utilizing scaffolding techniques is effective in improving students' explanatory skills and independent learning. This is evidenced by the increase in pretest posttest scores, N-Gain values, MANOVA test results, and the test of between subjects effects in both the experimental and control classes.

Regarding explanatory skills, the average student score in the experimental

class increased from 63.12 to 80.53, while the control class increased from 56.49 to 72.19. The experimental class's N-Gain value of 0.43 was higher than the control class's value of 0.34. Furthermore, the results of the test of between-subjects effects showed a significance value of 0.024 ($<0,05$) indicating a significant difference in explanatory skills between the experimental and control classes. These findings suggest that the implementation of discovery learning integrated with deep learning and e-book assisted scaffolding is capable of enhancing students' ability to construct claims, evidence, and reasoning more effectively.

Improvements in explanatory skills occur because the discovery learning model provides students with opportunities to actively observe phenomena, formulate problems, collect data, and draw conclusions. These activities help students develop the ability to explain phenomena scientifically and logically.

4. Additional Analysis and Interpretation

Although the MANOVA results demonstrated significant differences between the experimental and control groups, further analyses could provide a more comprehensive understanding of the intervention effects. First, an Analysis of Covariance (ANCOVA) could be employed in future studies to control for differences in students' initial abilities by using pretest scores as covariates. The descriptive statistics showed that the experimental group had slightly higher pretest scores than the control group in both explanation skills and learning independence. Therefore, ANCOVA would allow researchers to estimate the treatment effect after adjusting for baseline differences and provide stronger evidence

regarding the effectiveness of the developed e-book (Kim, 2022).

Second, a more detailed analysis of students' explanation skills could be conducted by examining each component of the Claim–Evidence–Reasoning (CER) framework separately. The findings suggest that students demonstrated greater improvement in constructing claims compared with evidence and reasoning. This pattern indicates that students were relatively successful in identifying answers to scientific problems, but still experienced difficulties in linking evidence to scientific concepts through coherent reasoning. Previous studies have shown that students often find the reasoning component more challenging because it requires them to connect evidence with scientific principles and construct scientifically justified explanations (Sampson & Clark, 2008). For example, when students were asked to explain why the frequency of a vibration changes when the length of a pendulum is modified, most students were able to state a claim and provide observational evidence from simulations. However, fewer students were able to connect the evidence with relevant scientific principles to justify their conclusions. This finding highlights the importance of providing additional scaffolding focused on scientific reasoning processes (Belland, 2017).

Third, future studies may investigate whether the effectiveness of the e-book differs according to students' initial achievement levels. Interaction analyses between treatment conditions and students' prior knowledge could reveal whether the intervention is more beneficial for low-, medium-, or high-achieving learners. Such analyses would provide valuable information regarding the adaptability of scaffolding strategies and their suitability

for diverse student populations (Sweller et al., 2011).

In addition, the deep learning approach encourages students to understand concepts more deeply through analysis and reflection, so that students do not merely memorize concepts but are able to relate them to observed phenomena. The use of scaffolding techniques also assists students by providing gradual support in the form of guiding questions, reference tables, PhET simulations, and feedback that helps students connect claims, evidence, and reasoning.

Regarding self-directed learning, the average score of the experimental class increased from 70.15 to 83.00, while that of the control class increased from 64.98 to 76.21. The N-Gain score for the experimental class was 0.41, higher than that of the control class at 0.31. The results of the test for between-subjects effects also showed a significance value of 0.022 (<0.05), indicating a significant difference in learning autonomy between the experimental and control classes. These results demonstrate that the developed e-book is effective in enhancing students' learning autonomy.

The enhancement of independent learning is influenced by the integration of discovery learning, deep learning, and scaffolding into the learning process. Discovery learning encourages students to be more active in discovering concepts and solving problems independently. The deep learning approach helps students develop reflective skills, learning strategies, and self-assessment. Meanwhile, scaffolding provides gradual support that is slowly reduced so that students become accustomed to taking responsibility for their own learning process. The use of interactive e-books, CER-based

worksheets, PhET simulations, and group discussions also helps students become more active, confident, and focused in their learning.

The results of the MANOVA test showed a Hotelling's Trace significance value of 0.016 (<0.05), indicating that there was a significant difference in students' explanatory skills and learning independence between the experimental and control classes simultaneously. Furthermore, the effect size analysis results indicate values of 0.082 for explanatory skills and 0.085 for self-directed learning, both falling into the moderate category. Thus, the deep learning-based science e book utilizing scaffolding techniques has a sufficiently effective impact on improving students' explanatory skills and self directed learning. Based on the analysis of indicators, the greatest improvement in explanatory skills was observed in the "claim" aspect, while the "reasoning" aspect still showed a lower level of improvement because students continued to struggle to make in depth connections between evidence and scientific concepts. Regarding independent learning, the aspects that developed the most were learning initiative and responsibility, while the aspects of self-confidence and self-evaluation still require further practice and guidance. Nevertheless, the implementation of discovery learning integrated with deep learning using scaffolding techniques continues to have a positive impact on all indicators of students' explanatory skills and independent learning.

5. Research Limitations

Several limitations should be considered when interpreting the findings of this study. First, the study employed a

quasi-experimental design with non-random assignment of participants to the experimental and control groups. Although the groups were selected from the same school and received similar instructional content, differences in students' initial characteristics may still have influenced the results. Consequently, causal inferences should be interpreted with caution.

Second, teacher-related factors may have affected the implementation of the intervention. Variations in classroom management, instructional delivery, and familiarity with technology could have contributed to differences in student outcomes. Although efforts were made to standardize the learning process, the possibility of teacher-related bias cannot be completely eliminated.

Third, the intervention was conducted over a relatively short period consisting of three learning sessions. As a result, the observed improvements may primarily reflect short-term learning gains. Longer interventions are needed to determine whether the improvements in explanation skills and learning independence can be sustained over time.

In terms of external validity, the study was conducted in a single junior high school with a limited sample size. Therefore, the findings may not be fully generalizable to other educational settings, grade levels, subject areas, or student populations with different socio-cultural backgrounds. Future studies should involve larger and more diverse samples across multiple schools and regions to enhance the generalizability of the findings.

Despite these limitations, the results provide preliminary evidence that integrating discovery learning, deep

learning principles, and scaffolding techniques into an interactive science e-book can positively support the development of students' explanation skills and learning independence. Therefore, the findings contribute to the growing body of research on technology-enhanced science learning and provide a foundation for further investigation using more rigorous experimental designs.

CONCLUSION

This study developed a discovery-deep learning-based science e-book using scaffolding techniques for the topic of vibrations and waves and evaluated its feasibility, practicality, and effectiveness in improving students' explanation skills and learning independence. The results showed that the developed e-book was considered feasible by content and media experts, practical based on teacher and student responses, and effective in improving students' explanation skills and learning independence, as indicated by the MANOVA, N-Gain, and effect size analyses.

However, these conclusions are limited to the context of this study, which involved eighth-grade students at a single junior high school, focused on the topic of vibrations and waves, and was implemented over three learning sessions. Therefore, caution should be exercised when extending these findings to different grade levels, subject matters, educational contexts, or longer instructional periods.

Future research is recommended to replicate this study using randomized experimental designs, investigate the long-term retention of learning outcomes, examine the effectiveness of the e-book across diverse educational settings and science topics, and evaluate the cost-

effectiveness of large-scale implementation in schools. Such investigations would strengthen the evidence regarding the broader applicability and sustainability of discovery-deep learning e-books supported by scaffolding techniques.

REFERENCES

- Alfieri, L., Brooks, P. J., Aldrich, N. J., & Tenenbaum, H. R. (2011). Does discovery-based instruction enhance learning? *Journal of Educational Psychology*, 103(1), 1–18. <https://doi.org/10.1037/a0021017>
- Backfisch, I., Lachner, A., Stürmer, K., & Scheiter, K. (2021). Variability of Teachers' Technology Integration in the Classroom: A Matter of Utility. *Computers & Education*, 166, 104159. <https://doi.org/10.1016/j.compedu.2021.104159>
- Belland, B. R. (2017). *Instructional Scaffolding in STEM Education: Strategies and Efficacy Evidence*. Springer International Publishing. <https://doi.org/10.1007/978-3-319-02565-0>
- Berland, L. K., & McNeill, K. L. (2010). A Learning Progression for Scientific Argumentation: Understanding Student Work and Designing Supportive Instructional Contexts. *Science Education*, 94(5), 765–793. <https://doi.org/10.1002/sce.20402>
- Cheng, K.-H., & Tsai, C.-C. (2019). A Case Study of Immersive Virtual Field Trips in an Elementary Classroom: Students' Learning Experience and Teacher-Student Interaction Behaviors. *Computers & Education*, 140, 103600. <https://doi.org/10.1016/j.compedu.2019.103600>

- Cobo-Rendón, R., Bruna, Daniel; Lobos, K., & Díaz-Mujica, A. (2020). Modeling Self-Regulated Learning in University Students. *Frontiers in Psychology*, 11, 570. <https://doi.org/10.3389/fpsyg.2020.00570>
- Council, N. R. (2012). *Education for life and work: Developing transferable knowledge and skills in the 21st century*. The National Academies Press.
- Field, A. (2009). *Discovering Statistics Using SPSS* (3rd ed.). Sage Publications Ltd.
- Fitriani, N., Wahyudi, I., & Prasetyo, Z. K. (2022). Pengaruh Latihan Keterampilan Eksplanasi terhadap Pemahaman Konsep IPA Siswa SMP. *Jurnal Inovasi Pendidikan IPA*.
- Fosnot, C. T. (2013). *Constructivism: Theory, Perspectives, and Practice*. Teachers College Press.
- Fullan, M., Quinn, J., & McEachen, J. (2018). *Deep learning: Engage the world change the world*. Corwin Press.
- Ghozali, I. (2018). *Aplikasi Analisis Multivariate dengan Program IBM SPSS 25*. Badan Penerbit Universitas Diponegoro.
- Hair, J. F., Black, W. C., Babin, B. J., & Anderson, R. E. (2018). *Multivariate Data Analysis* (8th ed.). Cengage Learning EMEA.
- Hmelo-Silver, C. E., Bridges, S. M., & McKeown, J. M. (2019). Facilitating problem-based learning. In *The Wiley handbook of problem-based learning* (pp. 297–319). Wiley. <https://doi.org/10.1002/9781119173243.ch13>
- Hwang, G.-J., & Chien, S.-Y. (2022). Definition, Roles, and Potential of Deep Learning in Education. *Computers and Education: Artificial Intelligence*, 3, 100082. <https://doi.org/10.1016/j.caeai.2022.100082>
- Kim, Y. H. (2022). A Search for Music Teachers' Learning Community Management Plan to Enhance Their Expertise: Based on Focus Group Interview and IPA Matrix Analysis. *Korean Journal of Research in Music Education*, 51(2), 115–146. <https://doi.org/10.30775/KMES.51.2.115>
- Lin, Y.-T., Chen, C.-M., & Liu, T.-C. (2017). Effects of Digital Learning Materials on Students' Learning Outcomes. *Educational Technology Research and Development*, 65(5), 1263–1284. <https://doi.org/10.1007/s11423-017-9520-8>
- McNeill, K. L., & Krajcik, J. (2008). Scientific explanations: Characterizing and evaluating the effects of teachers' instructional practices on student learning. *Journal of Research in Science Teaching*, 45(1), 53–78. <https://doi.org/10.1002/TEA.20201>
- Sampson, V., & Clark, D. B. (2008). Assessment of the Ways Students Generate Arguments in Science Education: Current Perspectives and Recommendations for Future Directions. *Science Education*, 92(3), 447–472. <https://doi.org/10.1002/sce.20276>
- Sung, Y.-T., Yang, J.-M., & Lee, H.-Y. (2022). The Effects of Digital Learning on Student Engagement and Achievement: A Meta-Analysis. *Educational Psychology Review*, 34, 1–29. <https://doi.org/10.1007/s10648-021-09630-0>

- Sweller, J., Ayres, P., & Kalyuga, S. (2011). *Cognitive Load Theory*. Springer International Publishing. <https://doi.org/10.1007/978-1-4419-8126-4>
- Tabachnick, B. G., & Fidell, L. S. (2019). *Using Multivariate Statistics* (7th ed.). Pearson.
- Thiagarajan, S., Semmel, D. S., & Semmel, M. I. (1974). *Instructional Development for Training Teachers of Exceptional Children: A Sourcebook*. Indiana University.
- Van de Pol, J., Volman, M., & Beishuizen, J. (2024). Scaffolding in teacher–student interaction: A decade of research and future directions. *Educational Psychology Review*, 36(2), 1–24.
- Zimmerman, B. J. (2008). Investigating Self-Regulation and Motivation: Historical Background, Methodological Developments, and Future Prospects. *American Educational Research Journal*, 45(1), 166–183. <https://doi.org/10.3102/0002831207312909>