Lensa: Jurnal Kependidikan Fisika
Penerbit: Universitas Pendidikan Mandalika
https://e-journal.undikma.ac.id/index.php/Lensa/index

June 2026, Vol. 14, No. 1
e-ISSN: 2686-0937
pp. 157–178

Developing a Discovery Learning-Based Interactive E-LKPD (Electronic Student Worksheet) for Teaching Work and Energy in Senior High School Physics

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Abstract

This study aimed to develop and evaluate a Discovery Learning-based interactive E-LKPD (*Elektronik-Lembar Kerja Peserta Didik*/Electronic Student Worksheet) for teaching work and energy in Grade X senior high school physics. The study employed a research and development design using the ADDIE model, consisting of analysis, design, development, implementation, and evaluation stages. The participants were 30 Grade X students at SMA Swasta Gajah Mada Medan, including 10 students in a small-group trial and 20 students in a large-group trial. Data were collected through expert validation sheets, teacher and student response questionnaires, observation sheets, and a 20-item learning outcome test. Product validity was examined using expert judgment and Cohen's Kappa, practicality was analyzed using response percentages, and potential effectiveness was evaluated through pretest-posttest analysis, paired-samples t-test, Cohen's d, and normalized gain. The results showed substantial agreement among validators, with Cohen's Kappa of 0.674. The overall practicality score reached 86.0%, indicating a practical category. Students' mean score increased from 48.5 on the pretest to 93.0 on the posttest, with $t(19) = 18.42$, $p < 0.001$, Cohen's $d = 2.31$, and N-gain = 0.86. These findings indicate that the developed E-LKPD is valid, practical, and has potential effectiveness for supporting students' learning of work and energy concepts.

Keywords: Discovery learning; E-LKPD; Work and energy; Physics learning; Research and development

How to cite: Padang, H. P., & Ramadhani, I. (2026). Developing a Discovery Learning-Based Interactive E-LKPD (Electronic Student Worksheet) for Teaching Work and Energy in Senior High School Physics. *Lensa: Jurnal Kependidikan Fisika*, *14*(1), 157–178. https://doi.org/10.33394/j-lkf.v14i1.17349

INTRODUCTION

Science education plays a central role in preparing students to understand natural phenomena, reason with evidence, and apply scientific concepts to real-life situations. In physics learning, this role becomes particularly important because physics requires students not only to remember formulas, but also to construct conceptual relationships among variables, interpret representations, and explain physical events through scientific reasoning. However, students' science competence in Indonesia remains a concern. The Programme for International Student Assessment (PISA) 2018 reported that Indonesian students obtained a science literacy score of 396, which was below the OECD average of 489 and lower than Indonesia's score of 403 in 2015 (OECD, 2019). This result indicates that many students still experience difficulty in understanding scientific concepts deeply and applying them in contextual situations. In physics classrooms, this problem is often associated with teacher-centered instruction, limited contextual learning experiences, and the dominance of memorization and mathematical problem solving without meaningful conceptual understanding.

Work and energy are fundamental topics in senior high school physics, but they are also among the concepts that frequently generate misconceptions. Students often struggle to distinguish work in the scientific sense from effort in everyday language. They may also confuse energy with force, power, heat, or motion, and fail to recognize energy transfer and transformation across different physical systems. Previous studies have shown that students' alternative conceptions of energy tend to persist even after instruction, particularly when learning activities do not explicitly confront misconceptions or support conceptual reconstruction (Sari et al., 2021; Zhou & Traynor, 2022; Widodo et al., 2024). Zhou and Traynor (2022) emphasized that learning progressions and cognitive diagnostic approaches are needed to identify which attributes of energy students have mastered and where conceptual difficulties remain. Similarly, Widodo et al. (2024) reported that students' conceptions can collapse when they are required to solve physics problems that demand integrated conceptual reasoning. These findings suggest that the teaching of work and energy should move beyond formula substitution and provide opportunities for students to build, test, and revise their understanding.

A related issue is that students' misconceptions are often rooted in fragmented mental models and in the gap between everyday experience and scientific explanation. When students interpret energy only from visible motion or daily-life expressions, they may overlook abstract features such as energy storage, transfer, system boundaries, and conservation. Conceptual change literature suggests that effective learning requires instructional activities that make students' prior conceptions visible and then guide them to compare those conceptions with scientific evidence (Tanner & Allen, 2005; Jenkin & Howard, 2019). In physics classrooms, this means that students need structured experiences that encourage prediction, observation, explanation, representation, and reflection. Without such experiences, students may remain dependent on teacher explanations and may not develop a coherent understanding of work and energy concepts.

The same problem was identified in the preliminary study conducted at SMA Swasta Gajah Mada Medan. Interviews with the Grade X physics teacher showed that students tended to be passive during the learning process and relied heavily on teacher explanations to understand physics concepts. The analysis of students' daily test scores on work and energy in the 2024/2025 academic year showed an average score of 68, while the school's minimum mastery criterion was 75. Moreover, 65% of students had not achieved the expected mastery level. A learning motivation questionnaire administered to 30 students also showed that 70% of students perceived physics as difficult and less interesting, while 66.7% stated that the worksheets used in class had not helped them discover concepts independently. The worksheets used in the classroom were still mostly printed materials containing summaries and problem exercises, with limited exploratory activities and limited integration of digital technology. These findings indicate the need for learning materials that can promote active participation, independent concept discovery, and meaningful engagement with physics concepts.

One instructional approach that can address this need is Discovery Learning, particularly when implemented with appropriate guidance. Discovery Learning positions students as active learners who investigate problems, collect information, analyze data, and draw conclusions. Nevertheless, pure discovery without sufficient support may create cognitive overload, especially when students are dealing with abstract physics concepts. Therefore, guided discovery is more appropriate for school physics learning because it combines student exploration with teacher scaffolding. Research syntheses and empirical studies have shown that inquiry-based and guided discovery approaches can improve students' conceptual understanding, scientific reasoning, and higher-order thinking when the level of guidance is properly calibrated (Furtak et al., 2012; Rachman & Jauhariyah, 2020; Gunawan et al., 2019; Winarti & Sari, 2020). In this approach, the teacher does not directly provide final answers, but facilitates learning through guiding questions, problem situations, data interpretation tasks, and reflective discussion.

The relevance of guided discovery in physics learning is also supported by studies showing its positive effect on science process skills and learning outcomes. Gunawan et al. (2019) found that guided inquiry supported by virtual laboratory activities enhanced students' science process skills in learning heat concepts. Winarti and Sari (2020) also reported an improvement in students' science process skills through guided inquiry learning in wave, vibration, and sound topics. These studies suggest that students learn physics more effectively when they are engaged in structured investigation rather than passive reception of information. For the topic of work and energy, guided discovery can help students identify problems, formulate hypotheses, observe phenomena, interpret relationships among variables, and conclude the principles of work-energy and energy conservation through meaningful learning activities.

Alongside the need for more active learning models, the development of digital learning materials has become increasingly important in science education. Digital and electronic worksheets can transform conventional worksheets into interactive learning resources that integrate text, images, videos, simulations, guiding questions, feedback, and formative assessment. Unlike printed worksheets that often contain only explanations and exercises, electronic worksheets can support students' exploration and reflection through multimedia and interactive tasks. Previous studies have shown that digital worksheets can enhance engagement, learning autonomy, science process skills, conceptual understanding, and digital literacy when they are aligned with learning objectives and embedded in active learning sequences (Febriansyah et al., 2021; Petters, 2021; Suryanto et al., 2022; Distrik et al., 2024). However, the effectiveness of digital worksheets depends strongly on their pedagogical design. Digital media alone does not guarantee meaningful learning if the activities only reproduce conventional exercises in digital form.

Electronic student worksheets, known in the Indonesian context as E-LKPD, are particularly relevant because they can combine guided discovery syntax with interactive digital features. E-LKPD allows learning materials, activities, and evaluation tasks to be presented interactively so that students can engage with concepts more actively and independently. Through E-LKPD, students can be guided step by step from stimulation and problem identification to data collection, data processing, verification, and conclusion drawing. The use of platforms such as Liveworksheets can also provide flexible access and support students in completing worksheet-based activities in a digital environment. Discovery-oriented e-worksheets have been reported to support students' higher-order thinking, scientific attitudes, decision-making skills, and conceptual understanding in science learning (Muhammad et al., 2022; Soenarko et al., 2022; Ramadan et al., 2020). Suryanto et al. (2022) showed that physics e-worksheets integrated with augmented reality could improve students' problem-solving skills, while Distrik et al. (2024) demonstrated that digital problem-based worksheets could address conceptual understanding problems and enhance digital literacy. These findings show that electronic worksheets can function not merely as digital exercises, but as learning environments that structure students' inquiry and reasoning.

Previous studies have also reported the effectiveness of E-LKPD and discovery-oriented worksheets in physics learning. Studies by Anjarwati et al. (2021), Sari et al. (2021), Rahmawati et al. (2022), and other studies conducted between 2020 and 2025 indicate that E-LKPD integrated with Discovery Learning can improve students' learning outcomes, conceptual understanding, and learning activities. However, many of these studies focused mainly on product validity and practicality, used limited samples, or examined topics other than work and energy. In addition, previous findings on learning improvement are not always consistent because of differences in research design, student characteristics, instructional implementation, and digital platforms used. Research that specifically integrates Discovery Learning-based E-LKPD with Liveworksheets in senior high school physics, particularly in the topic of work and energy and in a private school context, remains limited.

Based on the literature and preliminary needs analysis, there is a clear need to develop an interactive E-LKPD that integrates Discovery Learning syntax with digital worksheet features to support students' conceptual understanding of work and energy. Although several studies have examined discovery-based worksheets and digital learning media, empirical evidence is still needed regarding the validity, practicality, and potential effectiveness of Liveworksheets-assisted E-LKPD in senior high school physics learning. Addressing this gap is important because work and energy concepts require students to connect formulas, representations, and physical reasoning, while guided discovery activities can provide a structured pathway for students to build those connections.

Study Purpose and Research Questions

This study aimed to develop a Discovery Learning-based E-LKPD assisted by Liveworksheets for the topic of work and energy in Grade X senior high school physics. The study focused on three main aspects of product development: validity, practicality, and potential effectiveness. Validity was examined through expert judgment to determine whether the content, language, presentation, media design, and Discovery Learning syntax were appropriate for physics learning. Practicality was examined through teacher and student responses after product implementation. Potential effectiveness was analyzed by comparing students' learning outcomes before and after using the developed E-LKPD through a pretest-posttest design. Accordingly, this study was guided by the following research questions:

1. How valid is the Discovery Learning-based E-LKPD assisted by Liveworksheets for teaching work and energy in Grade X senior high school physics?

2. How practical is the developed E-LKPD based on teacher and student responses during limited implementation?
3. To what extent does the use of the developed E-LKPD potentially improve students' learning outcomes on the topic of work and energy?

Novelty of the Current Study

The novelty of the current study lies in the integration of Discovery Learning syntax with an interactive Liveworksheets-assisted E-LKPD specifically designed for the topic of work and energy in Grade X physics learning. Previous studies have examined electronic worksheets, guided discovery, and digital learning media in science and physics education. However, many of them have focused mainly on product feasibility, general science topics, or digital worksheet development without providing specific evidence on work and energy learning in a senior high school physics context. This study addresses that gap by developing an E-LKPD that structures students' learning activities according to the stages of Discovery Learning, including stimulation, problem identification, data collection, data processing, verification, and conclusion drawing.

Another contribution of this study is its attempt to connect product development with empirical classroom evidence. Rather than reporting only expert validation and user responses, this study also examined students' learning improvement through pretest and posttest analysis, supported by normalized gain and effect size interpretation. Although the one-group pretest-posttest design does not allow strong causal claims, the findings can provide initial evidence regarding the potential effectiveness of Liveworksheets-assisted E-LKPD in supporting students' conceptual learning of work and energy. Therefore, this study contributes to the development of interactive physics learning materials that combine guided discovery pedagogy, digital worksheet features, and concept-oriented learning activities in a private senior high school context.

METHODS

Research Design

This study employed a research and development (R&D) design using the ADDIE model, which consists of five stages: Analysis, Design, Development, Implementation, and Evaluation (Branch, 2009). The ADDIE model was selected because it provides a systematic framework for developing instructional products, particularly digital learning materials that require needs analysis, iterative design, expert validation, limited implementation, and evaluation. The product developed in this study was a Discovery Learning-based electronic student worksheet assisted by Liveworksheets for the topic of work and energy in Grade X senior high school physics.

In addition to product development, this study applied a one-group pretest-posttest design to examine the potential effectiveness of the developed E-LKPD in improving students' learning outcomes. This design is commonly used in preliminary educational intervention studies to compare participants' performance before and after treatment, although it has limitations in controlling threats to internal validity because it does not involve a comparison group (Campbell & Stanley, 1963; Creswell & Creswell, 2018). Therefore, the effectiveness findings in this study were interpreted cautiously and were not intended to establish strong causal claims.

The overall development procedure adopted in this study is presented in Figure 1.

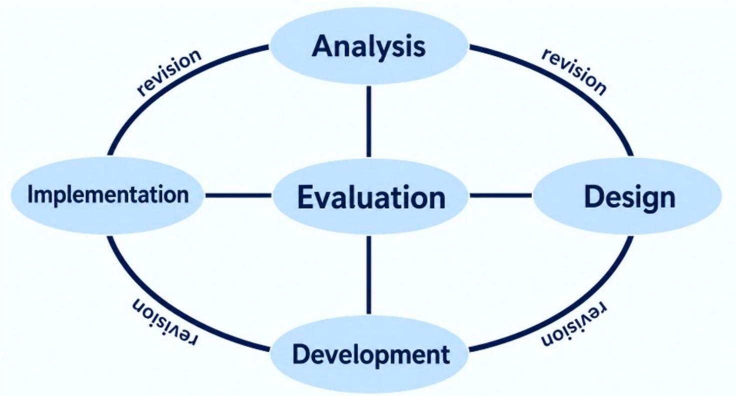


Figure 1. ADDIE Development Procedure

Figure 1 illustrates the iterative nature of the ADDIE model used in this study. The development process began with analysis to identify learning problems, student needs, curriculum demands, and the limitations of existing worksheets. The results of this stage informed the design of the E-LKPD, including the organization of learning activities, visual layout, assessment components, and integration of Discovery Learning syntax. The designed prototype was then developed using Liveworksheets and validated by experts before being implemented in small-group and large-group trials. Evaluation was conducted across all stages, not only at the end of the process, so that expert feedback, student responses, and implementation results could be used to revise and improve the E-LKPD before drawing conclusions about its validity, practicality, and potential effectiveness.

Research Context and Participants

The study was conducted at SMA Swasta Gajah Mada Medan during the 2025/2026 academic year. The research participants were Grade X students who were involved in the limited implementation of the developed E-LKPD. A total of 30 students participated in the product trial, consisting of 10 students in the small-group trial and 20 students in the large-group trial. The small-group trial was used to identify students' initial responses, usability issues, and practical limitations of the product. The large-group trial was used to examine the practicality and potential effectiveness of the revised product in a classroom implementation setting.

The participants were selected using purposive sampling based on three criteria: students were officially enrolled in Grade X, had completed prerequisite learning related to basic mechanics, and were willing to participate in all stages of the study. The use of purposive sampling was aligned with the purpose of educational product development, which focuses on evaluating the feasibility and usability of a product within a relevant instructional context.

Development Procedure

The development of the E-LKPD followed the five stages of the ADDIE model. The first stage was analysis. At this stage, the researchers conducted a preliminary needs analysis through teacher interviews, classroom observation, curriculum analysis, and student questionnaires. The analysis focused on students' learning difficulties in physics, the use of existing worksheets, the need for digital learning materials, and the suitability of the work and energy topic for Discovery Learning-based activities. The preliminary findings showed that students tended to be passive, relied heavily on teacher explanations, and had difficulty understanding work and energy concepts. The printed worksheets used in the classroom were also limited in supporting exploration, concept discovery, and digital interaction.

The second stage was design. In this stage, the researchers designed the structure, content organization, learning activities, and assessment components of the E-LKPD. The E-LKPD was designed according to the stages of Discovery Learning: stimulation, problem identification, data collection, data processing, verification, and conclusion drawing. The researchers also prepared learning indicators, worksheet scenarios, visual layouts, instructions, formative questions, and learning outcome test items. The design stage ensured that the digital worksheet was aligned with the physics curriculum, the characteristics of Grade X students, and the conceptual demands of the work and energy topic.

The third stage was development. At this stage, the initial prototype of the E-LKPD was developed using Liveworksheets. The product included learning objectives, introductory phenomena, conceptual explanations, guided questions, student activities, visual materials, and interactive tasks. After the prototype had been completed, it was validated by expert validators in terms of content, language, presentation, media design, and alignment with Discovery Learning syntax. The comments and suggestions from the validators were used to revise the product before implementation.

The fourth stage was implementation. The revised E-LKPD was first tested in a small-group trial involving 10 students. This trial aimed to examine the clarity of instructions, ease of access, layout readability, student engagement, and technical usability of the worksheet. Based on the results of the small-group trial, further revisions were made. The improved version of the E-LKPD was then implemented in a large-group trial involving 20 students. During this stage, students completed the learning activities using the E-LKPD, and data were collected through response questionnaires, observation, pretest, and posttest.

The fifth stage was evaluation. Evaluation was conducted throughout the development process and at the end of implementation. Formative evaluation was conducted during expert validation and small-group trials to improve the product. Summative evaluation was conducted after the large-group implementation to determine the validity, practicality, and potential effectiveness of the developed E-LKPD.

Product Description

The product developed in this study was a Discovery Learning-based E-LKPD for the topic of work and energy. The worksheet was designed to guide students in learning the concepts of work, kinetic energy, potential energy, the work-energy theorem, and the law of conservation of mechanical energy. Each learning activity was organized according to Discovery Learning syntax. In the stimulation stage, students were presented with contextual phenomena related to work and energy. In the problem identification stage, students were guided to formulate questions or problems based on the observed phenomena. In the data collection and data processing stages, students completed guided activities, interpreted information, and analyzed relationships among physical quantities. In the verification stage, students compared their findings with relevant physics concepts. In the conclusion drawing stage, students summarized the concepts they had constructed during the learning process.

Liveworksheets was used as the digital platform because it allowed the worksheet to be accessed online and provided interactive task formats. The platform supported students in completing worksheet-based learning activities through digital devices. The use of Liveworksheets was intended to increase learning flexibility, support student engagement, and facilitate interactive learning activities in physics.

Research Instruments

Several instruments were used to collect data in this study: expert validation sheets, teacher and student response questionnaires, observation sheets, and a learning outcome test. The expert validation sheet was used to evaluate the quality of the E-LKPD. The aspects assessed included content relevance, language clarity, presentation, media design, and the appropriateness of Discovery Learning syntax. The validation results were used to determine product feasibility and to guide product revision. Inter-rater agreement among validators was analyzed using Cohen's Kappa to examine the consistency of expert judgments beyond chance agreement (Cohen, 1960).

The teacher and student response questionnaires were used to examine the practicality of the E-LKPD. The questionnaires were developed using a five-point Likert scale ranging from strongly disagree to strongly agree. The practicality aspects included ease of use, clarity of instructions, attractiveness of presentation, usefulness of activities, accessibility, and support for independent learning.

The observation sheet was used to record the implementation of the E-LKPD during the learning process. The observation focused on the implementation of Discovery Learning stages, student participation, technical use of the worksheet, and the general flow of classroom activities.

The learning outcome test was used to measure students' understanding of work and energy before and after using the E-LKPD. The test consisted of 20 multiple-choice items developed based on learning indicators related to work, kinetic energy, potential energy, the work-energy theorem, conservation of mechanical energy, and applications of work and energy in daily life. The test items were reviewed by expert validators to ensure content relevance and alignment with the learning objectives. The quality of the test was also examined through item analysis, including item difficulty, discrimination index, and reliability. The reliability of the test was analyzed using KR-20 or Cronbach's Alpha, with a reliability coefficient of 0.70 or higher considered acceptable.

Data Collection Procedure

Data collection was carried out in several stages. First, preliminary data were collected through teacher interviews, student questionnaires, and document analysis of students' previous learning outcomes. These data were used to identify learning problems and determine the need for E-LKPD development. Second, the initial E-LKPD prototype was validated by experts. The validators assessed the product and provided qualitative suggestions for improvement. Third, the product was revised based on validation results and then tested in a small-group trial. Student responses and practical issues identified during this trial were used for further revision.

After the revision had been completed, the E-LKPD was implemented in a large-group trial. Before using the E-LKPD, students completed a pretest to measure their initial understanding of work and energy. During the learning process, students used the E-LKPD according to the Discovery Learning stages. After all learning activities had been completed, students completed a posttest using the same content coverage as the pretest. Teacher and student response questionnaires were then administered to collect practicality data. Observational data were also collected to support the interpretation of implementation results.

Data Analysis

The data were analyzed quantitatively and qualitatively. Quantitative data included validation scores, practicality questionnaire scores, pretest scores, posttest scores, and normalized gain scores. Qualitative data consisted of validator comments, teacher feedback, student comments, and observation notes. These qualitative data were used to support product revision and to enrich the interpretation of the quantitative findings.

Product validity was analyzed based on expert judgment. The consistency of expert ratings was examined using Cohen's Kappa, which is commonly used to measure agreement between raters beyond chance agreement (Cohen, 1960). The Kappa coefficient was interpreted using the agreement categories proposed by Landis and Koch (1977): less than 0.00 = poor agreement, 0.00-0.20 = slight agreement, 0.21-0.40 = fair agreement, 0.41-0.60 = moderate agreement, 0.61-0.80 = substantial agreement, and 0.81-1.00 = almost perfect agreement. In this study, Cohen's Kappa was used to indicate inter-rater agreement, not as a direct measure of content validity.

The practicality of the E-LKPD was analyzed using percentage scores obtained from teacher and student response questionnaires. The percentage score was calculated by dividing the obtained score by the maximum possible score and multiplying the result by 100. The practicality criteria were categorized as follows: 81-100% = very practical, 61-80% = practical, 41-60% = moderately practical, 21-40% = less practical, and 0-20% = not practical.

Students' learning outcomes were analyzed by comparing pretest and posttest scores from the large-group trial. Before conducting the main statistical test, the normality of the pretest and posttest scores was examined using the Shapiro-Wilk test at a significance level of 0.05. If the data were normally distributed, a paired-samples t-test was used to determine whether there was a significant difference between pretest and posttest scores. If the data were not normally distributed, the Wilcoxon signed-rank test was used as a non-parametric alternative.

The potential effectiveness of the E-LKPD was also examined using the normalized gain score, which is widely used to estimate students' learning improvement by comparing actual gain with the maximum possible gain (Hake, 1998). The normalized gain was calculated by subtracting the pretest score from the posttest score and dividing the result by the difference between the maximum possible score and the pretest score. The normalized gain categories were interpreted as follows: $g \geq 0.70$ = high, $0.30 \leq g < 0.70$ = moderate, and $g < 0.30$ = low.

In addition, Cohen's d was calculated to estimate the effect size of the difference between pretest and posttest scores. The effect size was interpreted as small when d = 0.20, medium when d = 0.50, and large when d = 0.80 or higher (Cohen, 1988). A 95% confidence interval was also reported to strengthen the interpretation of the statistical results.

Ethical Considerations

The study was conducted after obtaining permission from SMA Swasta Gajah Mada Medan. The teacher and students were informed about the purpose and procedures of the study before data collection. Student participation was voluntary, and the data were used only for research purposes. The identities of the participants were kept confidential, and the results were reported in aggregate form to avoid identifying individual students.

RESULTS AND DISCUSSION

Overview of the Developed E-LKPD

This study produced a Discovery Learning-based electronic student worksheet assisted by Liveworksheets for the topic of work and energy in Grade X senior high school physics. The product was developed through the five stages of the ADDIE model: Analysis, Design, Development, Implementation, and Evaluation. The final E-LKPD was designed to support students in learning work and energy concepts through structured discovery activities, interactive digital tasks, and guided conceptual exploration.

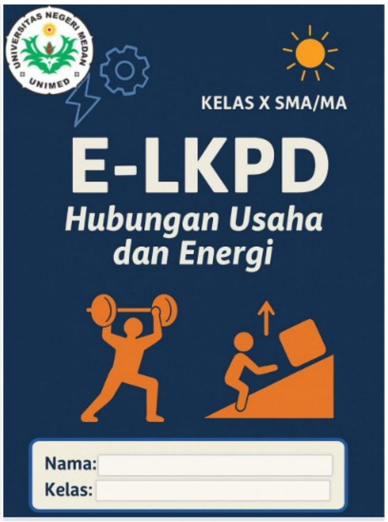
The developed E-LKPD consisted of four learning units covering the main subtopics of work and energy. Each unit was organized according to the Discovery Learning syntax, including stimulation, problem identification, data collection, data processing, verification, and conclusion drawing. The structure of the developed E-LKPD units is presented in Table 1.

Table 1. Structure of the developed Discovery Learning-based E-LKPD units

Unit	Topic	Main Learning Focus
E-LKPD 1	Work and Its Applications	Understanding the concept of work and its application in daily life.
E-LKPD 2	Kinetic Energy and Potential Energy	Identifying and analyzing forms of mechanical energy.
E-LKPD 3	Relationship between Work and Energy	Analyzing the relationship between work and changes in energy.
E-LKPD 4	Conservation of Mechanical Energy	Explaining and applying the law of conservation of mechanical energy.

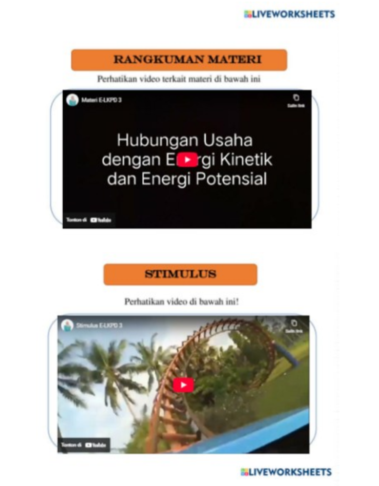
Table 1 shows that the developed E-LKPD was organized progressively from the basic concept of work to the conservation of mechanical energy. This structure was intended to help students build conceptual understanding gradually, beginning with contextual applications of work, continuing with the identification of mechanical energy forms, and ending with the analysis of work-energy relationships and conservation principles.

Cover page of the E-LKPD

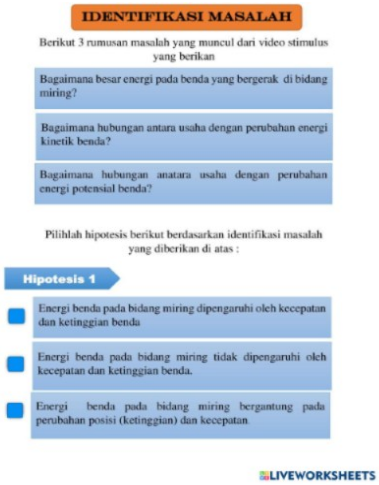


Student identity entry page

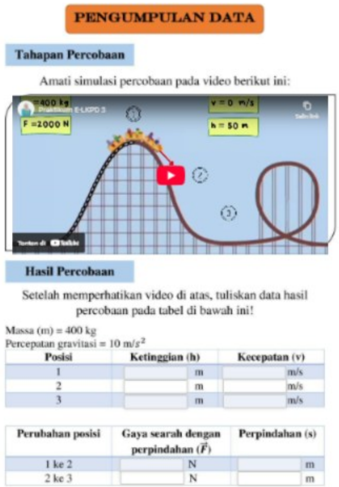
Instruction, learning outcomes, & objectives page



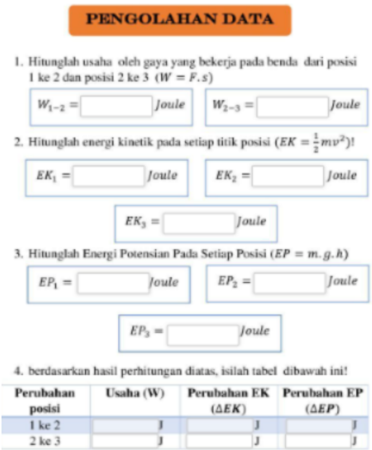
Page containing learning video and stimulation activities



Problem identification and hypothesis page



Page of the data collection stage



Page of the data processing stage

Page of the verification stage

Page containing the conclusion stage

Figure 2. Examples of the developed Discovery Learning-based E-LKPD units

Figure 2 presents examples of the developed E-LKPD units used in this study. The worksheets were designed with topic-specific covers, visual elements, student identity fields, and contextual illustrations to help students recognize the sequence of learning activities. The use of Liveworksheets allowed the worksheet format to be transformed into an interactive digital worksheet that could be accessed and completed online.

Results of Product Development Based on the ADDIE Stages

The analysis stage showed that students needed digital learning materials that could support more active and independent learning. The preliminary study indicated that students tended to rely on teacher explanations and that the existing printed worksheets were limited in promoting concept discovery. These findings became the basis for developing an E-LKPD that integrated Discovery Learning syntax with interactive worksheet features.

In the design stage, the researchers prepared the E-LKPD structure, learning indicators, worksheet layout, interactive tasks, and assessment components. The worksheet activities were designed to guide students from observing contextual phenomena to formulating problems, collecting information, analyzing data, verifying concepts, and drawing conclusions. The design also considered readability, visual consistency, and alignment with the learning objectives of the work and energy topic.

In the development stage, the E-LKPD prototype was created using Liveworksheets. The prototype was then validated by experts to evaluate its content relevance, language, presentation, media design, and alignment with Discovery Learning syntax. Revisions were made based on expert feedback before the product was implemented with students.

In the implementation stage, the E-LKPD was tested in two phases. The first phase was a small-group trial involving 10 students, which was conducted to identify usability issues, clarity of instructions, and students' initial responses to the digital worksheet. The second phase was a large-group trial involving 20 students, which was used to examine product practicality and potential effectiveness through teacher and student responses as well as pretest-posttest data.

In the evaluation stage, the product was reviewed based on validation results, practicality responses, observation notes, and students' learning outcomes. The results of this stage were used to determine whether the developed E-LKPD met the criteria for validity, practicality, and potential effectiveness.

Expert Validation Results

Expert validation was conducted to determine the feasibility of the developed E-LKPD before classroom implementation. The validation covered several aspects, including content feasibility, Discovery Learning components, readability, worksheet presentation, graphics, communication and media use, and design. The results showed that all assessed aspects obtained high validation scores, indicating that the product was appropriate for limited implementation in physics learning.

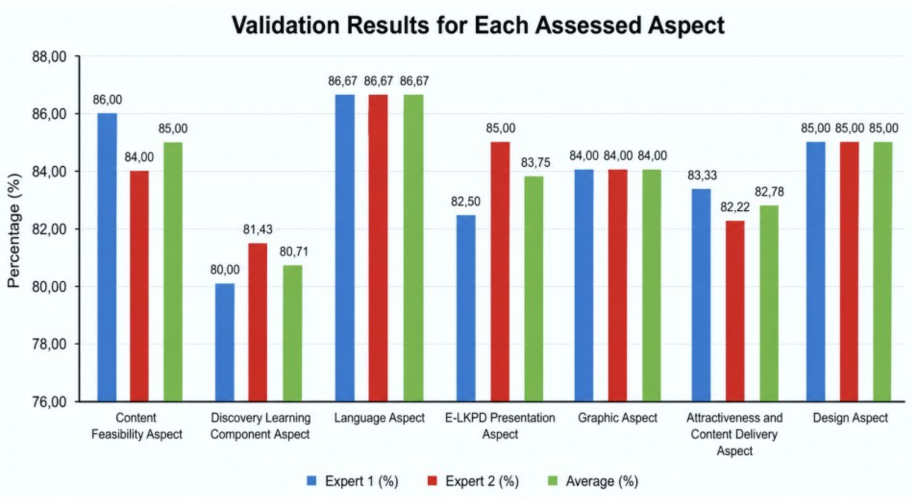


Figure 3. Expert validation results for each assessed aspect

Figure 3 shows that the validation scores across the assessed aspects were consistently high. The readability aspect obtained the highest average score, while the Discovery Learning component obtained the lowest score compared with the other aspects, although it still remained within an acceptable range. These results indicate that the E-LKPD was generally considered feasible in terms of content, presentation, language, media design, and instructional structure.

To examine the consistency of expert judgments, inter-rater agreement was analyzed using Cohen's Kappa. The result is presented in Table 2.

Table 2. Inter-rater agreement of expert validation

Statistic	Value
Cohen's Kappa	0.674
Standard error	0.104
p-value	< 0.001
Interpretation	Substantial agreement

The Cohen's Kappa coefficient was 0.674 with $p < 0.001$. Based on the agreement criteria, this value indicates substantial agreement among validators. This result suggests that the validators showed a consistent judgment regarding the feasibility of the developed E-LKPD. Therefore, the product was considered appropriate for implementation after revision based on expert suggestions.

Practicality Results

The practicality of the E-LKPD was examined based on teacher and student responses. The responses were collected from one teacher, 10 students in the small-group trial, and 20 students in the large-group trial. The results are presented in Table 3.

Table 3. Practicality results of the developed E-LKPD

Respondent	Percentage (%)	Category
Teacher	93.3	Very practical
Small group (n = 10)	81.7	Very practical
Large group (n = 20)	82.9	Very practical
Overall mean	86.0	Very practical

The teacher response reached 93.3%, which was categorized as very practical. The small-group trial obtained a practicality score of 81.7%, while the large-group trial obtained 82.9%. The overall practicality score was 86.0%, indicating that the developed E-LKPD was very practical for classroom use. These results suggest that the E-LKPD was considered easy to use, visually attractive, accessible, and useful for helping students learn work and energy concepts.

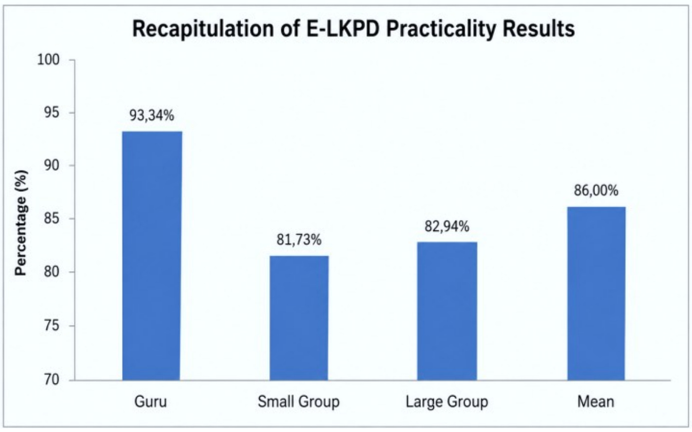


Figure 4. Recapitulation of E-LKPD practicality results

Figure 4 presents the practicality scores from the teacher, small-group trial, large-group trial, and overall mean. The teacher gave the highest practicality score, while the student responses in both small-group and large-group trials remained above the threshold for the "very practical" category. This pattern indicates that the E-LKPD was not only positively evaluated by the teacher, but also accepted by students during limited classroom implementation.

Students' Learning Outcomes

The potential effectiveness of the developed E-LKPD was examined using pretest and posttest scores from the large-group trial involving 20 students. Before conducting the paired-samples t-test, the normality of the pretest and posttest data was examined using the Shapiro-Wilk test. The results are presented in Table 4.

Table 4. Results of the Shapiro-Wilk normality test

Data	Shapiro-Wilk statistic	p-value	Category
Pretest	0.962	0.596	Normal
Posttest	0.954	0.441	Normal

The Shapiro-Wilk test showed that the pretest and posttest data were normally distributed, as both p-values were greater than 0.05. Therefore, a paired-samples t-test was used to examine the difference between students' pretest and posttest scores.

The descriptive statistics of students' learning outcomes are presented in Table 5.

Table 5. Descriptive statistics of students' learning outcomes

Variable	Mean	SD	Min-Max
Pretest	48.5	8.7	35-65
Posttest	93.0	4.9	85-100

The descriptive results showed an increase in students' mean score from 48.5 on the pretest to 93.0 on the posttest. The minimum and maximum scores also increased from 35-65 on the pretest to 85-100 on the posttest. This result indicates that students' learning outcomes improved after using the Discovery Learning-based E-LKPD.

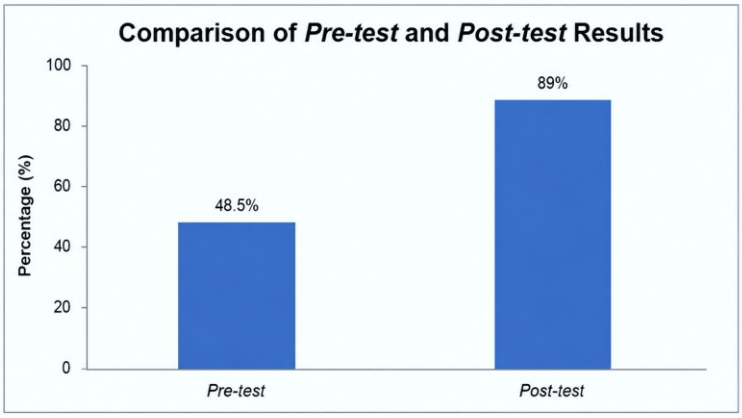


Figure 5. Comparison of students' pretest and posttest scores

Figure 5 illustrates the difference between students' mean pretest and posttest scores. The posttest mean was substantially higher than the pretest mean, indicating a positive change in students' performance after the implementation of the E-LKPD. The results of the paired-samples t-test are presented in Table 6.

Table 6. Results of the paired-samples t-test

Comparison	Mean difference	t	df	p-value	Cohen's d	95% CI
Posttest-Pretest	44.5	18.42	19	< 0.001	2.31	[39.4, 49.6]

The paired-samples t-test showed a significant difference between pretest and posttest scores, $t(19) = 18.42$, $p < 0.001$. The mean difference was 44.5 points, with a 95% confidence interval ranging from 39.4 to 49.6. The effect size, measured using Cohen's d, was 2.31, which indicates a very large effect. These results suggest that students demonstrated substantially higher learning outcomes after using the developed E-LKPD. However, because the study used a one-group pretest-posttest design without a control group, the result should be interpreted as evidence of potential effectiveness rather than definitive causal evidence.

Normalized Gain Analysis

In addition to the paired-samples t-test, students' learning improvement was analyzed using the normalized gain score. The results are presented in Table 7.

Table 7. Normalized gain results

Mean N-gain	SD	95% CI	Category
0.86	0.09	[0.81, 0.90]	High

The mean normalized gain was 0.86, with a standard deviation of 0.09 and a 95% confidence interval of [0.81, 0.90]. Based on the N-gain interpretation criteria, this value falls into the high category. This finding indicates that students experienced a high level of learning improvement after using the Discovery Learning-based E-LKPD assisted by Liveworksheets.

Sensitivity Analysis and Missing Data

A sensitivity analysis was conducted using a leave-one-out approach to examine whether the N-gain result was strongly influenced by a single participant. The analysis showed that the N-gain values remained within the range of 0.82 to 0.87. This result indicates that the learning improvement was relatively stable and was not driven only by one or two extreme scores.

There were no missing data in the large-group implementation. All 20 students completed the pretest, participated in the learning activities, and completed the posttest. Therefore, all participants in the large-group trial were included in the final analysis of learning outcomes.

Summary of Results

The results showed that the developed Discovery Learning-based E-LKPD assisted by Liveworksheets met the criteria of validity, practicality, and potential effectiveness. Expert validation produced a Cohen's Kappa coefficient of 0.674, indicating substantial agreement among validators. The practicality analysis showed an overall score of 86.0%, which was categorized as very practical. The pretest-posttest analysis showed a significant increase in students' learning outcomes, with a mean score improvement from 48.5 to 93.0, $t(19) = 18.42$, $p < 0.001$, and Cohen's $d = 2.31$. The normalized gain score was 0.86, indicating a high level of learning improvement. These findings suggest that the developed E-LKPD is feasible and practical for limited classroom implementation and has the potential to support students' learning outcomes on the topic of work and energy.

Discussion

The findings of this study indicate that the Discovery Learning-based E-LKPD assisted by Liveworksheets met the criteria of validity, practicality, and potential effectiveness for supporting Grade X students' learning of work and energy. The expert validation results showed substantial agreement among validators, while teacher and student responses indicated that the product was very practical for classroom use. The pretest-posttest results also showed a marked improvement in students' learning outcomes after using the developed E-LKPD. These findings suggest that a digital worksheet designed with clear instructional syntax, interactive features, and guided conceptual activities can support physics learning, particularly for topics that require students to connect concepts, representations, and problem-solving procedures.

The validity result shows that the developed E-LKPD was considered appropriate in terms of content, language, presentation, media design, and alignment with Discovery Learning syntax. This is important because the quality of an electronic worksheet depends not only on its digital format, but also on its instructional coherence. A digital worksheet may look attractive, but it will not necessarily support meaningful learning if the learning objectives, activities, questions, and assessment tasks are not pedagogically aligned. The substantial inter-rater agreement obtained in this study indicates that the validators had a consistent judgment regarding the feasibility of the product. This finding is consistent with previous studies showing that well-designed e-worksheets should integrate content accuracy, structured activities, visual clarity, and instructional scaffolding to support students' reasoning and conceptual understanding

(Muhammad et al., 2022; Soenarko et al., 2022; Suryanto et al., 2022; Distrik et al., 2024).

The practicality results also showed that the E-LKPD was positively evaluated by both the teacher and students. The high practicality score suggests that the product was easy to access, understandable, visually acceptable, and useful for supporting learning activities. This result is meaningful because practicality is a crucial requirement for digital learning materials. A learning product that is theoretically sound but difficult to use in real classrooms is unlikely to be adopted by teachers or accepted by students. In this study, the use of Liveworksheets helped transform worksheet-based learning into a more flexible and interactive format. This finding supports previous research indicating that digital worksheets can improve learning engagement and autonomy when they are accessible, clearly structured, and aligned with classroom learning processes (Febriansyah et al., 2021; Petters, 2021; Syar et al., 2023; Suniasih & Sujana, 2023).

The improvement in students' learning outcomes after the use of the E-LKPD can be explained through the instructional characteristics of guided Discovery Learning. The E-LKPD did not merely present concepts and exercises, but guided students through stages of stimulation, problem identification, data collection, data processing, verification, and conclusion drawing. This sequence encouraged students to participate actively in constructing their understanding rather than passively receiving information from the teacher. Previous studies and meta-analytic findings have shown that inquiry-based and guided discovery approaches are more likely to improve conceptual understanding and higher-order thinking when students receive sufficient scaffolding during the learning process (Furtak et al., 2012; Rachman & Jauhariyah, 2020). In this study, the structured prompts and guided activities in the E-LKPD may have helped students focus on relevant concepts, analyze relationships among variables, and formulate conclusions based on learning evidence.

The findings are also consistent with empirical studies in physics education showing that guided inquiry and discovery-oriented learning can improve students' science process skills, motivation, and learning outcomes. Gunawan et al. (2019) reported that guided inquiry supported by virtual laboratory activities enhanced students' science process skills, while Winarti and Sari (2020) found that guided inquiry improved students' science process skills in wave, vibration, and sound learning. Although the present study focused on work and energy rather than laboratory-based physics topics, the results show a similar pattern: students benefited from learning activities that combined exploration with structured guidance. This supports the argument that guided discovery is more appropriate than unguided discovery in school physics contexts, where students often need scaffolding to interpret abstract concepts and connect them with mathematical representations.

The relevance of the developed E-LKPD is particularly important for the topic of work and energy. Work and energy are conceptually demanding because students must distinguish scientific meanings from everyday meanings, identify energy transfer and transformation, and understand relationships among force, displacement, work, and mechanical energy. Previous research has shown that students often experience persistent misconceptions about energy concepts and may fail to apply energy principles consistently across contexts (Sari et al., 2021; Zhou & Traynor, 2022; Widodo et al., 2024). The E-LKPD developed in this study attempted to address these difficulties by presenting contextual phenomena, guided questions, and concept-oriented activities. These features may have helped students move beyond formula memorization and engage more directly with the conceptual structure of work and energy.

From a conceptual change perspective, the improvement in students' performance may also be related to the way the E-LKPD encouraged students to observe, predict, analyze, and verify ideas. Conceptual change requires students to become aware of their initial ideas, compare them with scientific explanations, and reconstruct their understanding through evidence-based reasoning (Tanner & Allen, 2005; Jenkin & Howard, 2019). The E-LKPD activities provided opportunities for this process by guiding students to examine physical situations, answer structured questions, and draw conclusions. This is relevant because misconceptions in physics often persist when instruction focuses only on formulas and final answers. By integrating digital interactivity with guided discovery tasks, the E-LKPD offered a learning environment that supported both engagement and conceptual reconstruction.

This study contributes to the development of digital physics learning materials in several ways. First, it provides an example of how Discovery Learning syntax can be embedded into an interactive E-LKPD using Liveworksheets. Second, it links product development with empirical classroom evidence through expert validation, practicality testing, and pretest-posttest analysis. Third, it focuses on the topic of work and energy, which is conceptually important but often difficult for students. Previous studies have reported the benefits of e-worksheets and discovery-based digital learning materials in science education (Muhammad et al., 2022; Soenarko et al., 2022; Suryanto et al., 2022; Distrik et al., 2024), but the present study adds context-specific evidence from senior high school physics learning in a private school setting.

Despite these positive findings, several limitations should be considered. The study used a one-group pretest-posttest design without a control group, so the improvement in students' learning outcomes cannot be attributed solely to the E-LKPD with strong causal certainty. Other factors, such as teacher facilitation, students' increased familiarity with the test format, the novelty of using a digital platform, and repeated exposure to the topic, may have contributed to the observed improvement. The sample size was also relatively small and came from one private senior high school, which limits the generalizability of the findings. Therefore, the effectiveness result should be interpreted as preliminary evidence of potential effectiveness rather than definitive proof of causal impact.

Future research should test the developed E-LKPD using a stronger research design, such as a quasi-experimental design with an equivalent control group. Larger samples from different school contexts are also needed to examine whether the product remains effective across varied student characteristics and learning environments. Further studies may also investigate the effect of Discovery Learning-based E-LKPD on other learning outcomes, such as conceptual understanding, science process skills, critical thinking, digital literacy, and learning motivation. In addition, qualitative data from student interviews or learning process analysis could provide deeper insight into how students interact with E-LKPD activities and how their understanding of work and energy develops during guided discovery learning.

CONCLUSION

This study developed a Discovery Learning-based E-LKPD assisted by Liveworksheets for the topic of work and energy in Grade X senior high school physics. The product was developed using the ADDIE model, which allowed the learning material to be designed, validated, revised, implemented, and evaluated systematically. The developed E-LKPD integrated Discovery Learning syntax with interactive digital worksheet features to support students in exploring work and energy concepts through guided activities, contextual problems, and structured conceptual tasks.

The findings showed that the developed E-LKPD met the criteria of validity, practicality, and potential effectiveness. Expert validation indicated substantial agreement among validators, suggesting that the product was feasible in terms of content, language, presentation, media design, and alignment with Discovery Learning syntax. The practicality results also showed that the E-LKPD was very practical based on teacher and student responses. In addition, the pretest-posttest results showed a significant improvement in students' learning outcomes, supported by a high normalized gain and a large effect size. These findings indicate that the developed E-LKPD has the potential to support students' learning of work and energy concepts in physics.

However, the findings should be interpreted cautiously because the study used a one-group pretest-posttest design, involved a relatively small number of participants, and was conducted in one private senior high school. Therefore, the results provide preliminary evidence of potential effectiveness rather than strong causal evidence. Future studies are recommended to apply a quasi-experimental or experimental design with a control group, involve larger and more diverse samples, and examine the impact of Discovery Learning-based E-LKPD on other learning outcomes such as conceptual understanding, critical thinking, science process skills, digital literacy, and learning motivation.

RECOMMENDATION

Based on the findings and limitations of this study, several recommendations can be proposed. Physics teachers are encouraged to use Discovery Learning-based E-LKPD as an alternative digital learning material to support active, guided, and concept-oriented learning, particularly for topics that require students to connect abstract concepts with contextual phenomena, such as work and energy. The use of Liveworksheets or similar interactive platforms should be accompanied by careful instructional design so that digital worksheets do not merely replace printed worksheets, but provide meaningful learning activities, guiding questions, formative tasks, and opportunities for students to construct concepts independently. For schools, the implementation of digital worksheets requires adequate technological support, internet access, and teacher readiness in designing and managing interactive learning activities. Future researchers are advised to test the developed E-LKPD using stronger research designs, such as quasi-experimental or experimental designs involving control groups, larger samples, and different school contexts, so that the effectiveness of the product can be examined more rigorously. Further studies may also explore the impact of Discovery Learning-based E-LKPD on other important learning outcomes, including conceptual understanding, critical thinking skills, science process skills, digital literacy, learning motivation, and long-term retention.

ACKNOWLEDGEMENT

The authors would like to express their sincere gratitude to the supervising lecturers, the principal, the physics teacher, and the Grade X students of SMA Swasta Gajah Mada Medan for their support, guidance, and participation throughout the research process.

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