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STEAM-Based E-LKPD to Enhance Learning Independence on States of Matter Topic

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Abstract

This study aimed to develop an E-LKPD based on the STEAM approach on the topic of changes in the state of matter to improve the learning independence of fourth-grade elementary school students. The study employed the 4D development model (Define, Design, Develop, Disseminate). The subjects in this study were five fourth-grade students at SDN 1 Wonocoyo, Pogalan Sub-district, Trenggalek District. The instruments used included expert validation sheets, student response questionnaires, and learning independence questionnaires. The validation results showed that the E-LKPD was highly feasible for use, with an average validation score of 90%. Student responses to the E-LKPD indicated a high level of engagement and interest, reaching 92%. In addition, students' learning independence scores increased significantly after using the E-LKPD, with a gain score of 0.47 (moderate category). Thus, the STEAM-based E-LKPD proved effective in enhancing the learning independence of fourth-grade students at SDN 1 Wonocoyo, Pogalan Sub-district, Trenggalek District.

INTRODUCTION

Learning Natural Science is an essential subject in elementary schools that aims to develop students' cognitive and psychomotor potential with a material focus on linking learning materials with students' daily experiences (Wati et al., 2022). Natural Science is considered crucial to improving the quality of education and producing a generation of students who are able to think critically, creatively, and logically. One of the main materials of Natural Science in elementary school is changes in the state of matter (solid, liquid, gas), which gives students the opportunity to gain direct experience by recognizing natural phenomena that occur around them (Nurjannah, 2024).

In the Merdeka Curriculum, mastery of this material is very important because it is considered the foundation for understanding science and its application in everyday life (Waseso et al., 2024). Even so, a number of previous studies have highlighted concrete problems in science learning, namely the science learning outcomes of elementary school students which are still relatively low. This is due to several factors, one of which is the learning method which is still teacher oriented. Trisnawaty & Slameto (2017) stated that the dominant lecture method makes students only become passive listeners. So that students' understanding of the concept of science is really minimal. This condition is exacerbated by the limitations of learning facilities and media in every elementary school.

Another study found that the lack of concrete learning media makes the science learning process feel boring for students. On the topic of changes in the state of matter, for example, many students have not been able to connect the concepts taught with real-world phenomena. In fact, science material is actually very close to the real world. Suparman (in Sihotang & Sibuea, 2015) one of the characteristics of teaching materials is Individualized Learning Materials, meaning that teaching materials are designed according to the abilities and characteristics of the students who are studying them (Jannah et al., 2020)

This is in line with the statement from the fourth-grade homeroom teacher at SDN 1 Wonocoyo who revealed that in learning about changes in the state of matter, only 1 student really understood the concept, while 4 other students could not apply it (around 80% of students' scores were below the KKM). Low interest in learning and rapid student boredom because the material is considered a lot and abstract are also factors causing suboptimal learning outcomes.

To overcome these problems, a more contextual and interactive learning approach is needed. The STEAM (Science, Technology, Engineering, Art, Mathematics) approach was chosen because it integrates science with technology, engineering, art, and mathematics in an integrated manner. According to Widyastuti (2022), STEAM emphasizes solving problems in the real world by showing students how lesson concepts are used to create systems or products that improve the quality

of human life. This approach is in accordance with the characteristics of 21st-century learning because it encourages students to develop critical thinking, creativity, collaboration, and problem-solving skills. Based on the results of a meta-analysis study by Angela & Zulyusri (2024), it is known that STEAM-based LKPD is suitable for use in 21st-century learning because it is adaptive and in accordance with the demands of globalization and students' needs to accommodate their creativity. With all its integration advantages, STEAM is expected to be able to make science materials such as changes in the form of objects more interesting and meaningful for students.

The development of information technology encourages the need for the use of digital learning media in 21st-century education. Hamidah & Mastoah (2025) explain that the digital era requires the education system to adapt technology in the learning process. One form of this is the use of electronic-based Student Worksheets (E-LKPD). Research shows that the use of E-LKPD provides flexibility in learning, increases student involvement, and allows for rapid feedback. Furthermore, Student Worksheets are designed to strengthen student involvement in the learning process. In other words, E-LKPD can be an interactive learning media that encourages active and independent learning according to the 21st century learning paradigm that is centered on students.

This study offers a novel contribution by combining the STEAM approach with digital learning tools (E-LKPD) tailored to elementary-level IPAS content. While prior research has explored STEAM or digital worksheets separately, this integration targeting students' learning independence on scientific concepts such as states of matter represents a specific and underexplored niche.

The advantage of the 4D model is that it does not take a relatively long time, because the stages are relatively not too complex. The weakness of the 4D model is that in the 4D model it only goes to the distribution stage, and there is no evaluation, where the evaluation in question is measuring the quality of the product that has been tested, the product quality test is carried out for the results before and after using the product.

METHODS

This research is a type of development research (Research and Development) which aims to produce learning media in the form of E-LKPD based on the STEAM approach and test its feasibility and effectiveness in improving student learning independence. The development model used is the 4D model developed by Thiagarajan, Semmel, and Semmel (Sugiyono, 2019), which consists of four stages, namely: Define, Design, Develop, and Disseminate.

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The 4-D model is a development model that can be used to develop various types of learning media. In this research, the development carried out was E-LKPD (Arkadiantika et al., 2020).

1. Define Stage

This stage is carried out to identify and analyze the needs in developing E-LKPD. Activities include analyzing the characteristics of grade IV elementary school students and analyzing learning materials on Changes in the Form of Objects in natural science subjects. Interviews with grade IV teachers and observations of the learning process were also carried out to determine the obstacles faced in the learning process and the need for contextual and interactive learning media.

2. Design Stage

At this stage, the initial design of E-LKPD is prepared based on the STEAM approach and takes into account the characteristics of science learning on the Changes in the Form of Objects material in elementary school. The material is arranged in an interactive digital form with an activity structure that refers to the 5M stages (Observing, Asking, Reasoning, Trying, and Communicating). In addition, research instruments such as expert validation sheets, student response questionnaires, and learning independence questionnaires are also developed in this stage.

3. Develop Stage

The E-LKPD design that has been made is validated by three experts, namely material experts, media experts, and learning experts. After being revised based on input from experts, the E-LKPD was tested on a limited basis to 5 fourth grade students at SDN 1 Wonocoyo, Pogalan District, Trenggalek Regency. At this stage, measurements of student learning independence were also carried out between before and after using the E-LKPD.

4. Disseminate Stage

This stage is carried out on a limited basis in the form of publication of research results and socialization to elementary school teachers in the MGMP forum or training. Dissemination also includes the distribution of E-LKPD to teachers for use in science learning activities.

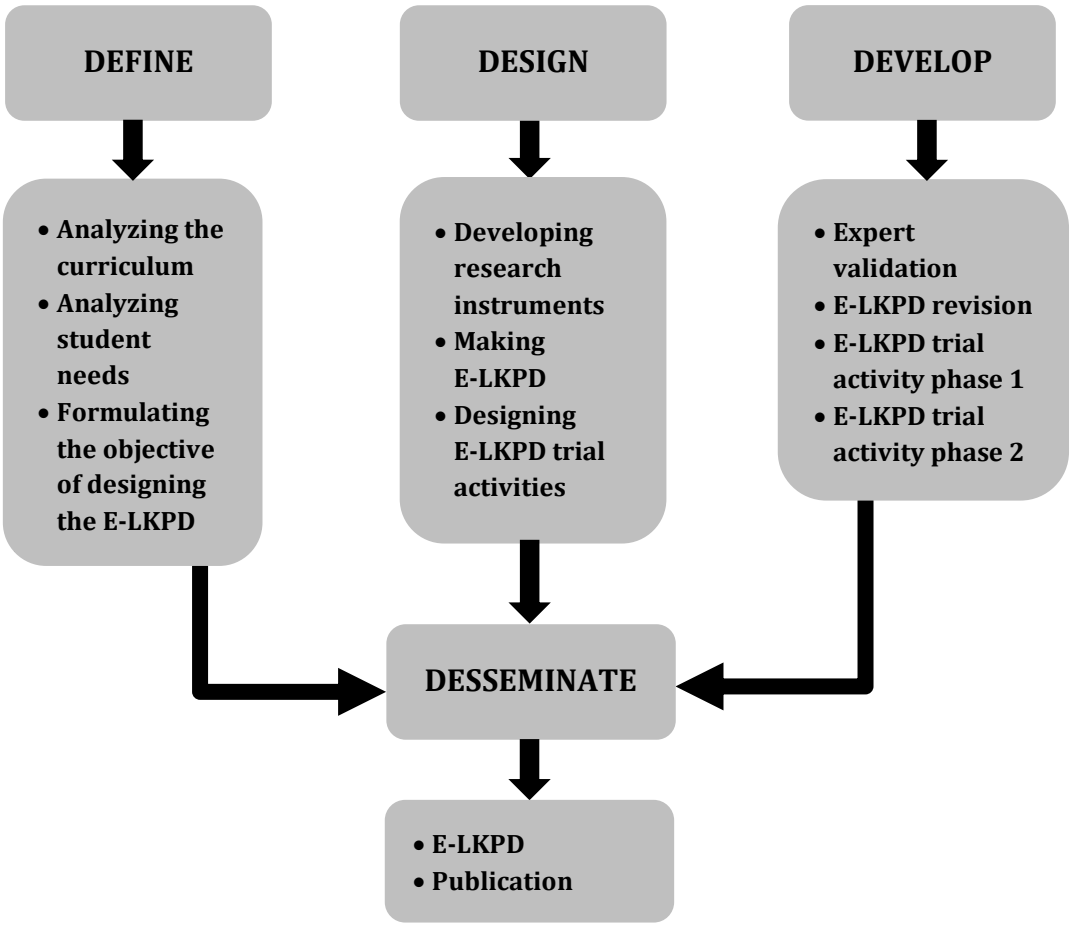

Figure 1. 4D Research Design in E-LKPD Development

5. Research Subjects and Location

The research was conducted at SDN 1 Wonocoyo, Pogalan District, Trenggalek Regency in the even semester of the 2024/2025 academic year. The research subjects consisted of 5 fourth-grade students. The validators included three expert validators consisting of 1 expert lecturer in Science PGSD material who teaches at Parahyangan Catholic University, 1 expert lecturer in learning media who teaches at Parahyangan Catholic University, and 1 fourth-grade elementary school teacher.

6. Data Collection Instruments

In this study, the instruments used were: (1) Expert validation sheet to measure the feasibility of E-LKPD based on aspects of content, presentation, language, visual appearance, and suitability with the STEAM approach, (2) Student response questionnaire containing closed statements using a 4-point Likert scale to assess the attractiveness, ease, and benefits of E-LKPD, and (3) Learning independence questionnaire compiled based on independence indicators according

to Nilson & Zimmerman (2023) consisting of learning initiative, self-regulation, and self-evaluation.

7. Data Analysis Techniques

The data obtained were analyzed descriptively quantitatively. Validation scores and student response questionnaires were converted into percentages to determine the feasibility and response categories. The effect of using E-LKPD on student learning independence was analyzed by comparing the average scores before and after using the media, and using a simple gain test.

RESULTS

This research produces a product in the form of E-LKPD based on the STEAM approach on the material of changes in the state of objects for grade IV elementary school students. The development process is carried out according to the stages of the 4D model (Define, Design, Develop, Disseminate) with a focus on product feasibility and increasing student learning independence. The following are the results obtained from the Design stage.

1. Expert Validation Results

Validation was carried out by three expert validators consisting of 1 lecturer expert in science material for elementary school teachers who teaches at Parahyangan Catholic University, 1 lecturer expert in learning media who teaches at Parahyangan Catholic University, and 1 grade IV elementary school teacher. The validation results scores for material, media and users are shown in table 1.

Table 1. Validation Results in Developing E-LKPD

Validator	Score (%)	Category
Material Expert	92%	Very suitable
Media Expert	88%	Suitable
Grade IV elementary school teacher	90%	Very suitable

Based on the table, it is known that the average validation score is 90% which is included in the very feasible category. This means that E-LKPD is very feasible to be used by grade IV elementary school students.

2. Limited Trial Results

The trial was conducted on 5 grade IV students at SDN 1 Wonocoyo, Pogalan sub-district, Trenggalek district. The use of E-LKPD was carried out during two meetings with a duration of 45 minutes. Students used E-LKPD individually and in small groups.

Figure 2. E-LKPD Trial in Class IV SDN 1 Wonocoyo

3. Student Response Results to E-LKPD

This student response questionnaire consists of aspects of appearance (visual and design), aspects of content (content and material), and aspects of general impression and satisfaction. The results of the student response questionnaire to E-LKPD show that 96% of students stated that E-LKPD is interesting and fun to use, 92% of students feel that E-LKPD is easy to understand and helps in understanding the material on changes in the state of objects and 88% of students stated that E-LKPD makes them more active in thinking and working together. The overall average of student responses is 92% in the Very Good category. This is in accordance with what is shown in the table below.

Table 2. Student Responses to E-LKPD Usage

Aspect	Assessment Indicator	Percentage	Category
Appearance (Visual and Design)	- Layout is neat and easy to navigate - Color combinations are attractive and not tiring - Font is readable and consistent - Use of images/icons is engaging	96%	Very Good
Content (Content and Material)	- Language is easy to understand - Material is in line with learning objectives - Content is structured and coherent - Examples are relevant and contextual	92%	Very Good
Interactivity and Involvement	- Encourages students to ask questions - Provides tasks that require critical thinking - Promotes teamwork/collaboration - Engages students in active learning	88%	Very Good
General Impression and Satisfaction	- Students feel helped in understanding the material - Students enjoy the learning process - Students are motivated to learn - Students recommend using it again	92%	Very Good

4. Student Learning Independence

The effect of using E-LKPD on student learning independence is measured through a questionnaire before and after use. The results are as in table 2 below.

Table 3. Results of Independence in Developing E-LKPD

learning independence Indicator	Previous Score	Score After	Gain Score	Improvement Category
Learning Initiative	66	82	0.47	Medium
Self-Regulation	62	80	0.48	Medium
Self Evaluation	60	78	0.45	Medium

The average gain score of students' learning independence is 0.47 which is included in the moderate category (Hake, 1999). This is in accordance with what is shown in the table below.

Table 4. Gain Score Categorization Table

N-Gain Value	Category
$g > 0.7$	High
$0.3 \leq g \leq 0.7$	Medium
$g < 0.3$	Low

Based on the scores before and after the scores obtained, the gain score of students' learning independence is 0.47, meaning that the use of STEAM-based E-LKPD contributes to increasing the learning independence of grade IV students.

DISCUSSION

1. Feasibility of STEAM-based E-LKPD

Validation was conducted by three expert validators consisting of 1 lecturer expert in science material for elementary school teacher education who teaches at Parahyangan Catholic University, 1 lecturer expert in learning media who teaches at Parahyangan Catholic University, and 1 grade IV elementary school teacher.

Validation by material experts produced a score of 92%, indicating that the content in E-LKPD is very appropriate with the Basic Competencies (KD) of the curriculum, learning objectives, and cognitive development of elementary school students. In addition, the material content has also integrated elements of the STEAM (Science, Technology, Engineering, Arts, Mathematics) approach quite optimally. The material developed not only emphasizes aspects of science and technology, but also contains elements of art and problem-solving skills that encourage students' critical thinking skills (Isnaningrum, & Marliani, 2025).

The success of material validation is also supported by the use of everyday contexts that are familiar to students, as recommended by the constructivist principle (Vygotsky, 1978; Piaget, 1972). The integration of STEAM concepts developed in LKPD allows students to learn holistically and contextually (Land, 2013).

Media validation by learning design experts shows that the visual appearance, navigation, color utilization, and user interface aspects of E-LKPD are included in the very feasible category with a score of 88%. This shows that the media has been designed according to the principles of effective and enjoyable instructional design for elementary school students (Smaldino et al., 2015). The appearance of E-LKPD uses attractive visual elements and considers the needs of elementary school-aged children who tend to be visual-auditory (Arsyad, 2015).

The media is also considered to have met the principles of interactivity and responsiveness to users, which are important in digital media based on independent learning (Mayer, 2009). The use of color, illustrations, and page layouts have been designed to support optimal learning focus and student engagement (Clark & Lyons, 2011).

Validation from users, in this case, grade IV elementary school teachers, gave a score of 90%, which is also categorized as very feasible. Teachers considered that this E-LKPD was very helpful in the learning process because it provided various activities, stimulated student involvement, and was easy to implement in the context of the Merdeka Curriculum class. Teachers also stated that this E-LKPD was able to support differentiated learning and foster student learning independence, which is an important part of the Pancasila student profile (Kemdikbud, 2022).

Teachers considered that this LKPD greatly supported them in creating active learning that was not only oriented towards the final results, but also on the students' thinking process during learning (Joyce et al., 2015). Moreover, the STEAM approach used helped teachers bridge cross-subject learning in an integrated manner.

The results of expert validation showed an average score of 90% (very feasible category). This finding is in line with research by Afrijal et al. (2023) which states that STEAM-based student worksheets are valid and effective in improving scientific literacy. This indicates that the integration of STEAM and digital approaches can create relevant and quality products.

2. Positive Student Responses to E-LKPD

The average value of the student response instrument was 92% of students stating that E-LKPD was interesting, easy, and supported thinking activities and collaboration. This supports the findings of Tristiana & Rusnilawati (2023) that the use of STEAM-based LKPD increases students' motivation, activeness, and science

learning outcomes. Dista et al. (2022) also showed a significant increase in student learning independence through STEAM learning.

In addition, the success of E-LKPD in attracting interest and facilitating active student involvement is in line with the results of research by Herlina & Rachmadyanti (2021) which stated that STEAM-based interactive media can build a fun and cognitively challenging learning atmosphere. This E-LKPD also provides space for students to explore, collaborate, and solve problems creatively. An important component in the STEAM approach according to Beers (2011) and Yakman (2012).

The learning context offered through E-LKPD encourages students to relate science material to real life, as emphasized by Hwang et al. (2015) that the integration of STEAM in science material can increase the relevance and engagement of learning. Thus, the results of these student responses not only reflect an interest in visual displays or digital navigation, but further demonstrate the success of the STEAM approach in activating students' cognitive and affective potential (Bybee, 2013).

Furthermore, the ease of use of E-LKPD is also a supporting factor for the success of independent learning. According to Pintrich (2004), ease of access and understanding of learning materials is closely related to increased self-efficacy and student learning regulation. This is reinforced by Kuo et al. (2014) who showed that intuitive digital learning design can strengthen students' learning independence in the context of e-learning and blended learning.

The high student response to cooperation in the learning process also reflects the implementation of the collaborative principle of STEAM learning, as explained by Quigley et al. (2017) that the engineering and arts aspects in STEAM encourage productive group work. Thus, the developed E-LKPD not only facilitates conceptual understanding but also fosters students' social skills such as communication, collaboration, and group responsibility (OECD, 2018). Overall, the student response value of 92% indicates that the developed E-LKPD has fulfilled the aspects of students' emotional and intellectual involvement, and supports 21st-century learning objectives that emphasize creativity, critical thinking, collaboration, and communication (P21, 2019). These findings strengthen the argument that the STEAM approach, when properly integrated into teaching tools such as E-LKPD, can be an effective strategy to improve the quality of science learning in elementary schools as a whole.

3. Increasing Learning Independence

The average gain score data of 0.47 indicates an increase in student independence in the moderate category. This figure is in line with the research of Amir & Purwanti (2021) which found that PjBL-based STEAM encourages critical and creative thinking in elementary school students. Ogara (2023) also explained

that the development of digital teaching materials has a positive impact on learning independence. In addition, Mulyasari & Sholikhah (2021) reported that STEM-based E-modules increase student learning independence during distance learning. This shows that integration with STEAM is very suitable for increasing student learning independence.

Furthermore, the gain value of 0.47 which is in the moderate category indicates that although the increase in learning independence is not at a high level, it has shown significant progress pedagogically. These results show that STEAM-based E-LKPD is able to facilitate a learning process that not only emphasizes knowledge transfer, but also strengthens students' independent learning character, as emphasized by Zimmerman (2002) that learning independence is formed through a cycle of planning, monitoring, and reflection on the learning process.

In the context of elementary schools, the achievement of this moderate gain is a positive indicator considering the age of students who are still at the concrete operational development stage (Piaget, 1972), so that learning interventions such as E-LKPD STEAM which are structured, visual, and problem-based can help form independent learning habits gradually (Murniati et al., 2020). The use of the STEAM approach in developing teaching materials also allows students to integrate cross-disciplinary knowledge with problem-solving activities, which encourages them to take more responsibility for their own learning process (Tsupros et al., 2009; Kim et al., 2014).

This finding is in line with research by Trisnawati & Hendayana (2022) which shows that student learning independence can be increased through interactive, exploratory, and project-based teaching media. In addition, the use of digital media such as E-LKPD allows students to learn at their own pace and style, which is an important component in forming self-directed learning (Knowles, 1975; Guglielmino, 2008).

In STEAM-based learning, students are required to not only understand the concept but also create real solutions to the problems given, thus forming responsibility, discipline, and learning initiative—all important aspects in learning independence (Lee, 2020; Rahayu et al., 2021). Thus, the achievement of a gain score in the moderate category still provides an indication that the approach applied is on the right track to strengthen students' independent learning competencies gradually and sustainably. Therefore, increasing learning independence through STEAM integration in E-LKPD can be used as an initial foothold for the development of other innovative learning media, as well as a basis for implementing more intensive learning strategies to facilitate the development of elementary school students' metacognitive abilities.

4. STEAM Integration and Learning Digitalization

This study shows how E-LKPD combines aspects of Science, Technology, Engineering, Arts, and Mathematics in an interactive digital way. This concept is similar to the STEAM idea by the Arts Education Partnership (2018) which emphasizes the relationship between disciplines to build active learning and experiences related to real-life contexts. The STEAM approach has also been shown to improve critical thinking skills and creativity as explained by Ferianto et al. (2024).

Digitization through E-LKPD and interactive modules provides independent involvement, according to the findings of Sinclair & Baccaglini Frank (2016) regarding the positive impact of digital technology on students' mathematical interactions, and Koretsky et al. (2018) who stated that guided inquiry worksheets strengthen students' sense-making.

5. Material on Changes in the State of Objects

The application of material on changes in the state of objects allows the use of simple experiments (observation, heating or cooling) packaged in digital format which is considered effective for internalizing the concept of material on changes in the state of objects. This is in line with the view of the NSTA (National Science Teaching Association, 2018) that science learning will be more meaningful when students experience the phenomena studied directly through exploratory and investigative activities.

In the context of STEAM-based E-LKPD, these simple experiments are developed in the form of interactive videos, simulations, or activity guides that can be accessed independently by students. The digital format allows the visualization of the process of changes in state, such as melting, freezing, evaporating, and condensing, to be more concrete and easier to understand, especially for elementary school students who are still in the concrete operational cognitive development stage (Piaget, 1972). This visual support can accelerate the process of understanding concepts through a multisensory approach, as explained by Mayer (2005) in multimedia learning theory.

Furthermore, STEAM-based experimental activities not only train conceptual understanding but also develop basic scientific skills, such as observing, classifying, measuring, predicting, and concluding. Such activities also strengthen the connection between science and everyday life, encouraging students to realize the relevance of scientific knowledge to their real experiences (Bybee, 2013; Beers, 2011). In a study by Sari, Pusparini, & Damayanti (2020), the use of digital experiments in science learning showed a significant increase in students' motivation and learning engagement.

In addition to the cognitive aspect, this approach also develops students' affective and psychomotor aspects. Practical activities, even in the form of digital

guides or simulations, encourage active involvement and high curiosity. According to Duschl et al. (2007), meaningful science learning must encourage students to ask questions, investigate, and reflect on the results of their observations. Within the STEAM framework, this reflection is extended into the process of creative thinking (art), problem solving (engineering), and the use of technology (digital tools), as explained by Yakman (2012).

Packaging experiments in digital format also supports the principle of differentiation in learning. Students with different learning speeds can access the material repeatedly, while teachers can use it as an enrichment or remedial medium. This provides high flexibility in implementing inclusive and adaptive learning to students' needs (Hwang et al., 2015). Thus, the application of simple digital-based experiments in the material of changes in the state of objects through STEAM-based E-LKPD has proven effective in helping internalize concepts, improving students' learning experiences, and fostering independence and scientific skills in an integrated manner. Learning is not only centered on teachers and materials, but on constructive activities carried out by students themselves, making them the main actors in the learning process according to the spirit of the Merdeka Curriculum. This study enriches local literature because it combines the STEAM approach, digitalization, and simple science materials in one product.

6. Increased Initiative, Self-Regulation, and Evaluation

All three showed moderate gain scores, reflecting progress in the aspect of independent learning. This supports Zimmerman's (2002) argument that interventions that trigger reflection, planning, and self-evaluation can increase student independence. Previous national research also found that scaffolding and contextual learning (Suhandi & Kurniasri, 2019) as well as lesson study can foster initiative and self-regulation in elementary school students.

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The increase in independent learning in the moderate category indicates that the approach used is on the right track, but still requires continuous reinforcement. According to Paris & Winograd (2003), learning independence develops gradually and is greatly influenced by the learning context that encourages students' autonomy, self-control, and self-confidence in making learning decisions. In this context, STEAM-based E-LKPD provides space for students to practice managing their own learning strategies through project-based, exploration, and problem-solving tasks.

Learning activities that integrate interdisciplinary elements in STEAM also require students to plan and monitor independently, for example when choosing an experimental approach, formulating hypotheses, or making observation reports. This supports the view of Schunk & Zimmerman (2012) that complex tasks that provide space for students' personal control are very effective in fostering self-regulated learning.

A study by Handayani & Istiqomah (2021) also shows that science learning designed with an exploratory and problem-based orientation, such as in the STEAM approach, can increase aspects of responsibility and discipline in independent learning. In addition, digital media support in E-LKPD allows students to access learning resources according to their individual needs and learning rhythms, strengthening the element of flexibility that is essential in independent learning (Garrison, 2003).

This finding is also in line with the results of research by Kusumastuti & Nurhadi (2022) which emphasizes the importance of learning that involves students' explicit self-reflection in each of their activities. By providing a reflection section in E-LKPD, students are trained to identify difficulties experienced, evaluate their learning strategies, and design improvement plans at the next stage. This is an important component in developing long-term autonomous learning capacity.

Overall, the gain scores obtained illustrate that the implementation of STEAM-based E-LKPD not only strengthens the understanding of material concepts but also contributes to the development of students' self-regulation and learning independence. This is important considering the direction of the Independent Curriculum policy which emphasizes the formation of students who are reflective, independent, and responsible for their own learning process.

7. Barriers and Strengthening Strategies

STEAM digitization requires infrastructure, teacher training, and media development according to the classroom context (Nuragnia et al., 2021; Milara & Cortés, 2024). This study minimizes barriers by providing initial training and product validation, but widespread implementation still requires systematic support. Dista et al. (2022) emphasized the need for ongoing assistance for the long-term success of STEAM in elementary schools.

The systemic support in question includes the involvement of various education stakeholders, such as the education office, principals, teacher communities, and educational technology providers. This is in line with the opinion of Mishra & Koehler (2006) in the TPACK framework, that the integration of technology into learning must consider pedagogical, content, and technological competencies in a balanced manner. Without ongoing coaching and training, teachers have the potential to have difficulty in developing and implementing STEAM-based digital media effectively in the classroom.

In addition, another challenge is ensuring that STEAM media and learning activities remain relevant to local conditions and student learning needs. According to the OECD (2020), a contextual and flexible educational approach is key to implementing sustainable educational innovation. Therefore, it is important to develop digital teaching tools, such as E-LKPD, which can be adapted to the conditions of school infrastructure and students' level of readiness to receive technology-based learning.

This study has tried to respond to these challenges by involving teachers in the validation and trial process, so that the resulting product is contextual and applicable. However, for replication on a larger scale, there needs to be a tiered training model and a systematic mentoring program as suggested by Trilling & Fadel (2009), so that digital transformation in the STEAM approach is not just a temporary project, but becomes part of the learning culture in elementary schools.

Thus, although the results of this study show the effectiveness of the digital STEAM approach through E-LKPD in increasing student learning independence, long-term success still depends on the continuity of support, readiness of the education ecosystem, and strengthening teacher capacity in designing 21st-century learning that is oriented towards cross-field integration and technology.

CONCLUSION

This research produced a STEAM-based E-LKPD (Electronic Student Worksheet) on the topic of changes in the state of objects for fourth-grade elementary school students. The development process followed the 4D model (Define, Design, Develop, Disseminate) and focused on assessing the product's feasibility and its effect on student learning independence. The conclusions are as follows: (1) Feasibility Based on Expert Validation: The average validation score from material, media, and user experts was 90%, categorized as very feasible. This indicates that the E-LKPD is highly appropriate in terms of content alignment with curriculum objectives, effective media presentation, and suitability for student use. (2) Positive Student Responses: The E-LKPD received an overall student response average of 92%, placing it in the Very Good category. Students rated the E-LKPD as visually attractive (96%), content-wise effective and understandable (92%), and engaging in promoting interactivity and collaboration (88%). The product was also well-received in terms of overall impression and learning satisfaction (92%). (3) Improvement in Student Learning Independence: The implementation of the E-LKPD led to a measurable improvement in student learning independence. The average N-Gain score was 0.47, which falls in the medium improvement category, based on Hake's (1999) criteria. Indicators such as learning initiative, self-regulation, and self-evaluation all showed meaningful progress after using the E-LKPD. The developed E-LKPD is not only feasible and well-received by students, but

also effective in enhancing their learning independence. This supports the integration of the STEAM approach in elementary science learning, particularly in making abstract concepts more engaging and meaningful through interdisciplinary, student-centered learning materials.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the author(s)

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