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Development of Neuroscience-Based E-LKPD on Material Human Mobility and the impact in Critical Thinking Abilities and Student Learning Outcomes

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Abstract

Innovation and variety in engaging learning media are essential for improving the success of the learning process. One of the innovations in learning media development is the creation of a neuroscience-based E-LKPD. This study aims to develop a neuroscience-based E-LKPD with characteristics that can increase student interest and support the learning process, as well as to examine its validity, practicality, and effectiveness. This research is a Research and Development (R&D) study using the ADDIE development model, which consists of the stages of analysis, design, development, implementation, and evaluation. The subjects of the study were students of SMA Kesatrian 1 Semarang, divided into a control group and an experimental group. Data were collected through interviews, questionnaires, and tests. The data included product feasibility assessments by material experts and media experts, product practicality evaluations by teachers and students, and product effectiveness based on critical thinking skills and student learning outcomes. Data analysis employed descriptive quantitative analysis, N-Gain tests, non-parametric statistical tests, and assessments of critical thinking ability indicators. The results of the validity test showed that material experts rated the product at 95% (very feasible) and media experts at 100% (very feasible). Practicality analysis showed a score of 93% (very practical) based on teacher responses and 97% (very practical) based on student responses in small-scale testing. The N-Gain test results indicated that the control class achieved a score of 54.30 (medium-low category, less effective), while the experimental class scored 69.38 (medium-high category, fairly effective). The classical completeness of the control class was 56% with an average score of 69.88, while the experimental class reached 81% with an average score of 80.66. Results of the non-parametric Mann–Whitney test revealed a significant difference between the learning outcomes of the control and experimental classes. Analysis of critical thinking ability indicators showed an average score of 58% for the control class and 81% for the experimental class. Based on these findings, it can be concluded that the developed neuroscience-based E-LKPD is feasible, practical, and effective in improving students' critical thinking skills and learning outcomes.

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INTRODUCTION

This research is based on interviews, observations, and an in-depth review of various previous studies regarding the needs of students and teachers in biology learning activities. The interviews and observations conducted by the researchers at SMA Kesatrian 1 Semarang revealed that the learning process still lacks the use of diverse technology-based learning media, highlighting the need for new innovations. Biology learning at SMA Kesatrian 1 Semarang still relies mainly on textbooks in the form of student worksheets (LKS), with occasional interludes such as monotonous videos explaining the material. The learning process also remains teacher-centered and lacks activities that can foster student interest and motivation. Interviews with students indicated that learning is often monotonous, less engaging, and sometimes boring. The textbooks used tend to be text-heavy, with uncolored images that appear less attractive, and there is little variation in the media employed.

Biology learning materials vary in their level of difficulty. Based on interviews with biology teachers and several students at Kesatrian 1 Senior High School in Semarang, it was found that one of the most difficult topics for students to understand, and which has a low cumulative KKM, is Human Mobility. This topic consists of two main sub-chapters discussing the Nervous System and the Muscular System. The material is considered complex because it covers a broad scope and connects the structure, function, and interrelationship of these two systems in the human body (Ardila et al., 2024). Specifically, the topic of Human Mobility includes the structure and function of the nervous system, the musculoskeletal system (skeleton, joints, and muscles), and how these two systems work together to enable movement. Due to its complexity, this topic requires learning media that can help students visualize and comprehend the material, as well as the application of engaging and enjoyable learning methods (Nurhadi et al., 2024).

Based on the information obtained, new innovations are needed in learning, one of which is the development of learning media that can attract interest and increase student motivation. One such innovation is the creation of Electronic Student Worksheets (E-LKPD) based on neuroscience. Neuroscience is the study of the nervous system and brain function, which has been extended into the field of education to support the learning process by understanding how the brain works and applying this knowledge to maximize brain function in learning (Thomas et al., 2019). Educational neuroscience links the functioning of the nervous system in the brain with appropriate learning activities, thereby creating opportunities to optimize neural stimulation and improve learning outcomes. It also emphasizes the regulation of emotions and emotional memory to further optimize the parts of the brain involved in learning. A neuroscience-based learning process highlights emotional stimulation and the cultivation of positive feelings while preventing stress in the brain, making learning more enjoyable and enhancing students' ability to understand and retain material over the long term (Sandrone & Carlson, 2021). The principles of neuroscience can be applied both in learning media and in the learning process itself, for example through the use of images, color composition, videos, animations, and engaging activities such as gamification (Muttaqin et al., 2024).

The development of Electronic Student Worksheets (E-LKPD) was also considered based on the results of interviews and observations with students, who stated that the use of technology facilitates the learning process. The integration of technology in education has become both a trend and a necessity, as it has proven to be efficient and flexible for learning (Hastini et al., 2020). Compared to printed LKPD, electronic LKPD offers additional advantages through the use of digital devices that can display videos, audio, and images to help students visualize abstract concepts, as well as animations that support comprehension and retention of the material (Aripin et al., 2020). The use of E-LKPD has been shown to significantly improve students' critical thinking skills and learning (Sani & Ambarwati, 2024; Zahroh & Yuliani, 2021). Moreover, E-LKPD can enhance student engagement, foster learning independence, and improve conceptual understanding, as students actively explore material through digital media. It can also increase learning motivation, particularly in online and blended learning environments (Nur et al., 2022).

Furthermore, to meet the demands of 21st-century skills such as critical thinking, creativity, communication, and collaboration as well as other equally important competencies such as digital literacy,

problem-solving, and adaptability, learning media are needed that can support students in developing these abilities. E-LKPD can be designed through systematic scientific steps to facilitate learning that enhances critical thinking skills and student learning outcomes, particularly when combined with neuroscience principles to maximize brain function. In addition, E-LKPD can be enriched with images, videos, graphs, and data that require in-depth analysis, thereby fostering the development of various 21st-century skills.

Based on the description above, the development of a neuroscience-based E-LKPD for the topic Human Mobility is grounded in the results of interviews and observations that analyzed the needs of students and teachers in biology learning. The electronic LKPD reflects the optimal use of digital technology in line with current educational developments. Its neuroscience foundation is intended to maximize brain stimulation, thereby supporting more effective learning. The selected material, categorized as difficult, necessitates innovative approaches in the learning process.

RESEARCH METHOD

This research is a Research and Development (R&D) study using the ADDIE development model, which consists of the stages of analysis, design, development, implementation, and evaluation. The subjects were students from SMA Kesatrian 1 Semarang, selected through purposive sampling. The small-scale trial involved 15 Grade XII-1 students who had previously studied the relevant material, while the large-scale trial involved Grade XI students, with Class XI-1 serving as the control group and Class XI-2 as the experimental group. Both groups were selected based on equivalent academic abilities and the same biology teacher.

Data were collected through interviews, questionnaires, and tests, using a pretest–posttest control group design. The research instruments, including the developed product, were validated by experts. The data collected included product validity (evaluated by material and media experts), product practicality (assessed by students from small scale trial and the teacher), and product effectiveness (measured through students' critical thinking skills and learning outcomes). Data analysis consisted of descriptive quantitative analysis, N-Gain tests, non-parametric statistical tests using SPSS Statistics, and assessments of critical thinking skill indicators.

RESULTS AND DISCUSSION

Characteristics of Neuroscience-Based E-LKPD

Various characteristics of the E-LKPD such as the use of colored images and animations, color composition, videos, and the addition of music links are adapted from neuroscience principles with the aim of creating learning media that can optimally stimulate brain function. In this way, the learning process is expected to become more effective and lead to improved learning outcomes.

E-LKPD is designed with colorful and representative images to make the material easier to understand and remember. In the learning process, images help visualize abstract concepts through illustrations and support context-based, applicable learning (Kustandi et al., 2021). They also enhance memory and retention, as visual information is quickly processed by the brain (Balemans et al., 2016). Moreover, images can capture attention, improve focus, support visual learners' preferences, and assist in analysis and reasoning (Li et al., 2017). From a scientific perspective, images stimulate the right hemisphere of the brain, which is more closely associated with imagination, visual processing, intuition, creativity, and art. However, neurological studies also emphasize that while the right hemisphere is dominant in visual processing, the left hemisphere plays a key role when visual information is transformed into language, concepts, or deeper analysis. Thus, the brain never works in isolation; rather, both hemispheres collaborate in the learning process (Tuarez et al., 2019).

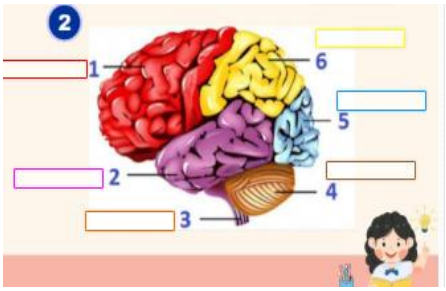

Figure 1. Image used in E-LKPD

The videos presented in E-LKPD are designed as engaging animations, making them enjoyable to watch and easier for students to understand. Videos and animations are considered highly effective and interactive learning media (Utaminingsih et al., 2024). Similar to images, they aid visualization, but they are often more effective and efficient due to their concise and interactive nature, which can increase motivation and interest in learning. Videos provide both visual and auditory input simultaneously, thereby strengthening comprehension (Farhan & Hadi Utama, 2024) . During the learning process, the left hemisphere of the brain processes narrative, language, and logic, while the right hemisphere processes visualization, color, movement, and shape (Wahyuningsih & Sunni, 2020). Videos and animations combine these elements—color, movement, and sound—which naturally capture students' attention and can activate the limbic system, the emotional center of the brain (Rolls, 2015). Because of their engaging nature, they can enhance interest and motivation in learning, allowing material to be retained more effectively in long-term memory (Norris, 2017).

Figure 2. Video used in E-LKPD

In images and videos, color is a key element that strongly influences the learning process. Color has the ability to attract attention by creating visual contrast, helping the brain distinguish important information from less important, and organizing or grouping information to provide visual (Nanglu & Sharma, 2024). Research shows that the brain more easily remembers information presented in color, as it creates a strong "visual trace" in long-term memory (Olurinola & Tayo, 2015). Color also enhances retention by stimulating dual information pathways simultaneously, similar to the way images support the visual learning style.

Additional music links connected to Spotify playlists are provided for students who enjoy studying or working while listening to music. Listening to music during learning activities can have positive effects, although these depend on factors such as the type of music, the nature of the learning task, and individual student characteristics (Serpil, 2015). The brain processes music through emotional, cognitive, and sensory pathways, influencing mood, concentration, and memory (Marbun, 2024). Individual preferences vary, some students prefer listening to music while studying or completing assignments, while others prefer silence. Therefore, in the developed E-LKPD, students are given the option to access or ignore the music links. For some learners, music can improve mood and motivation by stimulating dopamine, the so-called "happiness hormone" (Goltz & Sadakata, 2021). Music also activates the right hemisphere of the brain, which is associated with imagination, intuition, and creativity, particularly when listening to harmonious and melodic

music (Nugraha et al., 2024). Research further suggests that instrumental music, such as classical compositions, can enhance focus and concentration.

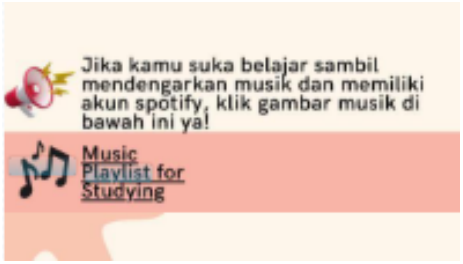

Figure 3. Link music in E-LKPD

E-LKPD is designed to be harmonious, well-organized, and user-friendly, making it attractive and enjoyable while increasing students' motivation to engage in learning (Münchow et al., 2017). Increased interest stimulates brain regions such as the nucleus accumbens, which releases dopamine associated with pleasure and satisfaction (Castro & Bruchas, 2019). Learning motivation is also driven by the hypothalamus, a brain structure responsible for curiosity and detecting rewarding stimuli (Burdakov & Peleg-Raibstein, 2020). Enjoyable learning experiences further stimulate the amygdala, which regulates emotions and helps prevent stress (Tyng et al., 2017). In addition, the limbic system—which integrates emotions, memory, and motivation—can function optimally in a positive learning environment, thereby enhancing interest and motivation and ultimately supporting the storage of information in long-term memory (Prima, 2018).

The material in the E-LKPD is aligned with the curriculum and learning objectives and is structured coherently. Several questions and problems are contextualized with everyday situations, allowing students to connect what they learn with real-life experiences. This approach reflects contextual learning, enabling students to construct knowledge more meaningfully and supporting the creation of learning memories that are easier to understand, retain, and store in long-term memory (Latief et al., 2014). The E-LKPD also includes a "Let's Examine" section containing questions designed to develop critical thinking skills. In this section, students are guided to practice six indicators of critical thinking as proposed by Facione (2023): interpretation, inference, analysis, explanation, evaluation, and self-regulation. This feature is specifically designed to foster and strengthen students' critical thinking abilities.

Validity of Neuroscience-Based E-LKPD

The validity of the Neuroscience-Based E-LKPD was evaluated by the material and media experts. The results of the validity analysis of the Neuroscience-Based E-LKPD by the material expert are presented in Table 1.

Table 1. Results of the Validity Analysis of the Neuroscience-Based E-LKPD by the Material Expert

Evaluation Aspect	Percentage	Category
Content Validity	92%	Very Valid
Language Validity	100%	Very Valid
Presentation Validity	92%	Very Valid
Overall Percentage	95%	Very Valid

The results of the material expert's validation covered three aspects: (1) content feasibility, (2) language feasibility, and (3) presentation. From these aspects, a total score of 45 was obtained, with an average score of 95%, as presented in Table 4.1. According to the validation criteria by Arikunto (2021), these results fall into the category of very valid.

The results of the validity analysis of the by Neuroscience-Based E-LKPD the media expert are presented in Table 2.

Table 2. Results of the Validity Analysis of the Neuroscience-Based E-LKPD by the Media Expert

Evaluation Aspect	Percentage	Category
Graphic	100%	Very Valid
Programming	100%	Very Valid
Overall Percentage	100%	Very Valid

Based on the media expert validation results, the E-LKPD developed by the researcher obtained a full score with a percentage of 100%, as shown in Table 4.2. The assessment covered two aspects: (1) programming and (2) graphics. These results fall into the very valid category and indicate that the product is highly feasible for implementation. Thus, the E-LKPD has met the required quality standards to support the learning process.

Practicality of Neuroscience-Based E-LKPD

The practicality of the neuroscience-based E-LKPD on Human Mobility material was obtained through a biology teacher response questionnaire and a student response questionnaire from the small-scale trial group. Practicality data were collected from the responses of the biology teacher and students of Class XI-2 at SMA Kesatrian 1 Semarang, as well as 15 students of Class XII-1 in the science program (MIPA) who served as the small-scale trial group. The teacher response questionnaire consisted of three aspects: presentation, usability, and content feasibility. Meanwhile, the student response questionnaire contained questions regarding the practicality of the E-LKPD. The results of the practicality analysis of the SETS-based e-magazine by the biology teacher are presented in Table 3.

Table 3. Results of the Practicality Analysis of Neuroscience-based E-LKPD by the Biology Teacher

Evaluation Aspect	Percentage	Category
Presentation	100%	Very practical
Usability	92%	Very practical
Content	88%	Very practical
Overall Percentage	93%	Very practical

The results of the teacher response questionnaire assessing the practicality of the neuroscience-based E-LKPD on Human Mobility obtained a total score of 37, with an average score percentage of 93%, which falls into the very practical category, as shown in Table 3.3. The teacher response questionnaire consisted of three aspects: (1) presentation, (2) usability, and (3) content feasibility, all of which received scores categorized as very practical. These results indicate that the neuroscience-based E-LKPD on Human Mobility developed by the researcher is of very high quality and meets the expectations and learning needs identified through previous interviews and observations. The biology teacher at SMA Kesatrian 1 Semarang stated that the neuroscience-based E-LKPD on Human Mobility is very well-developed, uses language that is easy to understand, and has an attractive appearance that can increase students' motivation in both learning and completing tasks.

The results of the practicality analysis of the Neuroscience-based E-LKPD by the students are presented in Table 4.

Table 4. Results of the Practicality Analysis of the Neuroscience-based E-LKPD by the Students

Evaluation Aspect	Percentage	Category
Practicality of E-LKPD	97%	Very practical

The responses of small-scale trial group for the development of the neuroscience-based E-LKPD on Human Mobility, showed an average percentage of 97%, which falls into the very practical category, as presented in Table 4.4. These results indicate that the neuroscience-based E-LKPD on Human Mobility developed by the researcher was able to attract students' interest and encourage their enthusiasm for learning. Students gave positive responses, stating that the E-LKPD greatly assisted them in the learning process of human mobility material. Furthermore, they noted that the E-LKPD supports independent learning and increases motivation, encouraging them to continuously explore the material being studied (Rosa et al., 2022).

Effectiveness of Neuroscience-based E-LKPD to Improve Critical Thinking Skill

Students' critical thinking skills after participating in the learning process using the neuroscience-based E-LKPD on Human Mobility were analyzed based on the achievement of critical thinking indicators. The results of the effectiveness analysis of the Neuroscience-based E-LKPD to improve students' critical thinking skill are presented in Table 5.

Table 5. Result of the Achievement of Critical Thinking Ability Indicators

Critical Thinking Ability Indicators	Control Class		Experimental Class	
	Pre Test	Post Test	Pre Test	Post Test
Explanation	26%	66%	25%	75%
Interpretation	37%	68%	45%	85%
Inference	31%	68%	28%	77%
Evaluation	44%	67%	49%	86%
Analysis	38%	73%	38%	76%
Self Regulation	43%	78%	44%	86%
Overall Percentage	37%	58%	38%	81%
Improvement	21%		43%	

The calculation results of the achievement scores for critical thinking skill indicators were aligned with the indicators proposed by Facione (2023). These achievement scores reflect students' critical thinking abilities, as measured through pre-test and post-test assessments, allowing the improvement in critical thinking skills to be evaluated based on indicator achievement.

The critical thinking indicators were divided into six aspects: interpretation, inference, explanation, analysis, evaluation, and self-regulation. The average indicator score on the control class pre-test was 37%, with the highest achievement in evaluation (44%) and the lowest in explanation (26%). Meanwhile, the experimental class pre-test produced an average of 38%, with the highest in evaluation (49%) and the lowest in explanation (25%). The relatively similar pre-test results between the two classes indicate that students' critical thinking skills in both groups were still low. In contrast, the control class post-test showed an average score of 58%, with the highest in self-regulation (78%) and the lowest in explanation (66%). The experimental class post-test, however, achieved an average score of 81%, with the highest in evaluation and self-regulation (both at 86%) and the lowest in explanation (75%).

These post-test results reveal a significant difference between the two classes, leading to the conclusion that the experimental class experienced a more substantial improvement in critical thinking skills. This demonstrates that the implementation of the neuroscience-based E-LKPD on the topic Human Mobility has proven effective in enhancing students' critical thinking abilities. Students' critical thinking was particularly fostered through the "Let's Examine" section of the E-LKPD, which encouraged them to think

critically, solve problems independently, and develop innovative solutions (Novitasari & Puspitawati, 2022).

Effectiveness of Neuroscience-based E-LKPD to Improve Student Learning Outcomes

Students' learning outcomes after participating in the learning process using the neuroscience-based E-LKPD on Human Mobility were analyzed through three types of tests: (1) the Classical Completion Results Test, (2) the N-gain Test, and (3) the Mann-Whitney Test. The classical completion results Test was used to determine and analyze students' learning achievement in relation to the predetermined Minimum Mastery Criteria (KKM). The N-gain Test was conducted to measure and analyze the improvement in learning outcomes based on students' pre-test and post-test results. Meanwhile, the Mann-Whitney Test was employed to analyze the differences in learning improvement between the control class and the experimental class after conducting prerequisite tests. The results of the effectiveness analysis of the Neuroscience-based E-LKPD to improve students' learning outcomes are presented in various table.

Table 6. Classical completion results

Data	Control Class		Experimental Class	
	Pre Test	Post Test	Pre Test	Post Test
KKM	75	75	75	75
Number of students completed	0	18	0	26
Number of students not completed	32	14	32	6
Classical completion results (%)	0%	56%	0%	81%

The results of the Classical completion results showed that the experimental class achieved a higher level of mastery compared to the control class. The pre-test results of both classes indicated a classical completion results percentage of 0%. However, in the post-test results, the control class reached a classical completion results of 56%, while the experimental class achieved 81%. These percentages were derived from the pre-test and post-test scores of both classes. The control class had an average pre-test score of 36.28, while the experimental class had an average of 38.28. These results were relatively similar, showing that none of the students had yet reached the Minimum Mastery Criteria (KKM) of 75. In contrast, the post-test results showed that the control class had an average score of 69.88, while the experimental class had a higher average score of 80.66. This demonstrates that the experimental class obtained significantly better results, leading to the conclusion that the implementation of the neuroscience-based E-LKPD in the experimental class proved effective in improving students' learning outcomes.

The next test conducted to determine the effectiveness of the developed product was the Mann-Whitney test. The Mann-Whitney test was used to examine whether there was a difference in learning outcomes between the control class and the experimental class (Qolby, 2020). Therefore, the data used in this test were limited to the post-test scores of both classes. If a significant difference was found between the two sets of post-test scores, then the difference in learning treatments could be considered effective. The results of the Mann-Whitney test showed a significant difference between the post-test scores of the control and experimental classes, with the experimental class achieving a higher average score. Thus, it can be concluded that the implementation of the neuroscience-based E-LKPD proved effective in improving student learning outcomes.

Table 7. N-Gain Test

N Gain Data	Cotrol Class	Experimental Class
Average	54,30	69,38
Scale	Moderate Low	Moderate High
Category	Less Effective	Quite Effective

The calculation of the N-gain test showed that the control class obtained an average gain score of

54.30, which falls into the medium-low category and is considered less effective. In contrast, the experimental class achieved an average N-gain score of 69.38, which is categorized as medium-high and considered moderately effective. The N-gain value reflects the increase in scores from the pretest to the posttest. The results of the N-gain test indicate that the experimental class achieved a higher average N-gain score with better criteria. Therefore, it can be concluded that the implementation of the neuroscience-integrated E-LKPD in the experimental class was proven effective in improving student learning outcomes.

Table 8. Student Response Questionnaire Results

Evaluation Aspect	Percentage	Category
Presentation	93%	Very Good
Usability	93%	Very Good
Learning Motivation and Learning Process	92%	Very Good
	93%	Very Good

The results of the student response questionnaire from the experimental class, used to assess the practicality of the neuroscience-based E-LKPD on the topic of Human Mobility, showed an average score percentage of 93%, which falls under the category of very good. Students also provided various positive comments regarding the E-LKPD, noting that it was interesting, innovative, unique, easy to understand, and very helpful in the learning process. However, some students pointed out a limitation of the E-LKPD, namely its electronic nature, which requires internet access, meaning that a stable internet connection is necessary. In addition to comments about the E-LKPD itself, students also shared feedback on the learning activities. The majority of responses were positive, highlighting that the use of videos and numerous images made the learning process more enjoyable, easier to understand due to the visualizations, and overall more engaging, interactive, and fun.

Overall, the results of the tests conducted indicate that the neuroscience-based E-LKPD developed is effective in improving both student learning outcomes and critical thinking skills. The effectiveness of the E-LKPD is influenced by various supporting characteristics, as previously described in the characteristics section. The neuroscience-based E-LKPD, which integrates elements such as color composition, images, animated videos, music links, and content designed to train critical thinking skills, has been proven effective in enhancing both critical thinking and learning outcomes. This is because the elements embedded in the E-LKPD are designed to maximize brain stimulation and create enjoyable learning and problem-solving conditions, thereby enabling the brain to function optimally.

CONCLUSION

Based on the research findings on the development of a neuroscience-based E-LKPD for the topic of Human Mobility, it can be concluded that the developed E-LKPD is highly valid, practical, and effective, with characteristics that align well with neuroscience principles.

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