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Effectiveness of a project-based learning digital booklet developed with the 4D model

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ABSTRACT

The role of education is very important in producing quality human resources, one of which is through improving the quality of biology learning in schools. This study aims to determine the effectiveness of digital booklet-based PjBL (Project-Based Learning) learning media on the developed motion system material. The low level of conceptual understanding among 11th-grade students at SMAN 2 Binjai is caused by conventional learning methods and the lack of interactive media. The research method applied is a development study (R&D) using the 4D model (Define, Design, Develop, and Disseminate). The effectiveness of the media is measured by comparing pretest and posttest results, which are then analyzed using the N-Gain formula. The research findings indicate that this digital booklet is quite effective in improving learning outcomes, conceptual understanding, and student mobility. The average N-Gain score was 0.73, which falls into the moderate category. Therefore, it is concluded that the developed booklet is effective in its use as an innovative learning solution in the classroom.

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INTRODUCTION

Education is a systematic and planned process aimed at creating a conducive learning environment where students can actively improve their learning abilities (Pratama & Hidayatullah, 2024). Education plays a crucial role in producing quality human resources. The application of science and technology (IPTEK) in education has given rise to various learning innovations, including the use of learning media (Yana & Khairuna, 2024). Learning media can refer to anything that can convey messages, stimulate students' thoughts, feelings, attention, and desires,

thereby improving learning outcomes (Annatasya & Prismana, 2023). One effective form of media is a pocket booklet, which can convey information systematically and visually, thereby enhancing students' understanding of abstract concepts, such as the human locomotion system.

The dependent variables in this study were the conceptual understanding, learning outcomes, and mobility of 11th-grade students in the human locomotion system topic. Conceptual understanding involves students' ability to identify, analyze, and apply knowledge about the structure and function of the locomotion system. Learning outcomes encompass students' cognitive achievements, measured through formative and summative assessments. Mobility refers to students' ability to move and actively interact during the learning process, supporting the development of motor and collaborative skills. Researchers chose to measure mobility as one of the dependent variables because the human locomotor system inherently focuses on the mechanisms of body movement involving muscles and bones. Therefore, conceptual understanding should not only be theoretical but also reflected in students' ability to simulate or apply movement practically. In the context of the research title "Effectiveness of a Project-Based Learning Digital Booklet Developed with the 4D Model," measuring mobility is a key indicator for evaluating the effectiveness of PjBL-based digital booklets. The 4D model (Define, Design, Develop, Disseminate) enables the development of media that supports interactive project activities, such as locomotor simulations, which can enhance students' physical engagement and holistic understanding of abstract biological concepts.

This dependent variable plays an essential role in biology education, as a sound conceptual understanding enables students to develop learning strategies aligned with the material, retain knowledge accurately, and apply it in everyday life (Miskonsepsi et al., 2021). Optimal learning outcomes contribute to the achievement of higher-order thinking skills (HOTS), such as critical thinking, which are crucial for understanding scientific concepts and solving real-world problems (Zubaidah et al., 2017; Mahanal & Zubaidah, 2017). Meanwhile, student mobility supports the development of creative ideas, collaboration, and interaction with the environment, thus producing adaptive and innovative human resources (Rahmadanti et al., 2022; Salsabilah Ramadanis & Ibnu Muthi, 2024). Measuring movement mobility specifically strengthens this role by connecting biological theory to practical applications, ensuring that students not only understand concepts cognitively but also integrate them with physical activity, aligning with the goal of the digital PjBL booklet to create dynamic and contextual learning.

Based on initial observations in grade XI of SMAN 2 Binjai, more than 60% of students demonstrated low conceptual understanding of the locomotion system material, as evidenced by formative assessment scores and teacher interviews (Sinaga et al., 2025a; Sinaga et al., 2025b). This impacts suboptimal learning outcomes and low student mobility, where students tend to be passive and less involved in the learning process. This problem is also reflected in students' difficulty in retaining long-term knowledge, which hinders the development of critical thinking skills and the application of biological concepts in real contexts. Low mobility, for example, is evident in students' inability to accurately simulate muscle or bone movements, which exacerbates misconceptions and reduces the effectiveness of conventional learning.

The biology topic covered is the human locomotor system, which consists of active components (muscles attached to the skeleton) and passive components (bones that form the skeleton). Human movement is caused by muscle contractions that mobilize bones (Tresnaasih, 2020). This topic is often considered challenging due to its complex subtopics, such as identifying muscle types, describing muscle structure, muscle function, and muscle anatomical location. Students require active involvement and creativity to understand the locomotor system, yet many students suffer from misconceptions regarding the structure and function of the human musculoskeletal system (Rohmah & Setiani, 2022; Miskonsepsi et al., 2021).

Main contributing factors include conventional, less interactive learning approaches, minimal active student engagement, and limited use of interactive learning media (Sinaga et al., 2025a). Furthermore, limited class hours, students' cognitive development levels, unsupportive learning environments, and inadequate supporting facilities exacerbate these problems (Mukra & Nasution, 2017). The lack of visual and contextual media also leads to low student interest and engagement, thus hindering conceptual understanding and mobility in biology learning.

To address this problem, a solution is proposed: the development of learning media in the form of digital booklets based on Project-Based Learning (PjBL). Digital booklets, as visual media, can be accessed flexibly and support technology-based learning, while PjBL provides a contextual approach through real-life projects that actively engage students. The integration of the two is expected to provide an engaging and meaningful learning alternative, aligned with students' need for access to technology-based learning.

Project-Based Learning (PjBL) is an innovative teaching approach that emphasizes contextual learning through complex tasks (Wulandari et al., 2023). Its advantages include: a) Increasing student motivation; b) Practicing problem-solving in learning and everyday life; c) Enhancing collaborative skills between teachers and students; d) Managing resources from various media; e) Optimizing student abilities (Matondang et al., 2024; Sutarini et al., 2024). PjBL-based booklets, as visual media, reinforce abstract concepts and support independent and collaborative learning. The relationship with the dependent variable is that PjBL and booklets can enhance conceptual understanding through contextual projects, improve learning outcomes by practicing critical thinking skills (Pasaribu et al., 2025), and increase student mobility through active engagement and the development of creative ideas (Rahmadanti et al., 2022). This approach also considers the subject matter, lesson hours, students' cognitive levels, learning environment, and supporting facilities (Mukra & Nasution, 2017).

Previous research has shown that PjBL is effective in improving students' understanding and critical thinking skills through digital media (Pasaribu et al., 2025; Amanda et al., 2025). Other studies have found that booklets as a learning medium help reduce misconceptions in biology concepts (Yana & Khairuna, 2024; Annatasya & Prismana, 2023). Furthermore, the application of PjBL in science learning has been shown to motivate students and enhance collaboration (Matondang et al., 2024; Sutarini et al., 2024). However, these studies have focused primarily on elementary school or general subjects, with a lack of integration of digital media specifically for high school biology.

The novelty of this research lies in the development of a PjBL-based digital booklet specifically designed for the human locomotion system at the high school level. It integrates interactive visual elements to address misconceptions and low student mobility. Unlike previous, more general research, this study emphasizes academic contributions in expanding the application of the digital media-based PjBL model to contextual biology learning, with a focus on increasing HOTS (Hot and Simple Sensitiveness) and flexible accessibility in public school settings such as SMAN 2 Binjai (Amanda et al., 2025b). It also offers an innovative solution to address the limitations of interactive media in schools with limited facilities. This study aims to develop learning media in the form of a PjBL-based booklet on the locomotion system material to improve conceptual understanding, learning outcomes, and mobility of class XI students at SMAN 2 Binjai.

RESEARCH METHODS

Research Design

This research applied a quantitative approach with a focus on testing the effectiveness of an already developed PjBL-based digital booklet. The booklet was previously developed using the 4D development model (Define, Design, Develop, and Disseminate), but this study specifically reports the dissemination stage. The define stage includes analyzing needs, learners, tasks, concepts, and

learning objectives. The design stage involves preparing materials, learning devices, evaluation instruments, and creating the initial design of the booklet media. At the development stage, expert validation and product trials are conducted on a limited scale. Finally, the disseminate stage was carried out to determine the effectiveness of the developed media. The research used a quasi-experimental design with a one-group pretest–posttest design to measure the improvement in students' conceptual understanding, learning outcomes, and mobility after using the booklet. The independent variable is the use of the PjBL-based digital booklet, while the dependent variables are students' conceptual understanding, learning outcomes, and mobility on the motion system material. This research was conducted at SMA Negeri 2 Binjai, located at Jalan Padang No. 08, Rambung Dalam Village, South Binjai District, Binjai City, North Sumatra Province. The independent variable in this study is the use of PjBL-based booklets, while the dependent variable is concept understanding, learning outcomes, and student mobility on the material of the motion system.

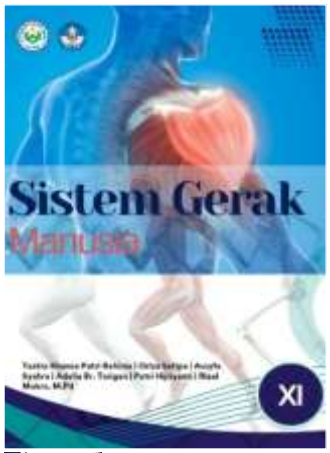

Figure 1. Movement System Booklet

Population and Samples

The population in this study was all students in class XI of the Science study program at SMA Negeri 2 Binjai, which consisted of five classes. The sample in this study was class XI IPA 3, which amounted to 25 students. The sample selection was carried out using a purposive sampling technique, which is a deliberate selection based on certain considerations that are aligned with the research objectives. Class XI IPA 3 was chosen because it meets the criteria of participation readiness, has representation of the characteristics of students in class XI IPA, and allows the implementation of learning media trials optimally. The class became the subject in the process of testing the effectiveness of booklet media based on Project-Based Learning (PjBL) on Motion System material.

Figure 2. Condition of students in class

Instruments

This research instrument includes three main types of tools, namely: (1) a multiple-choice test of 20 questions that measures students' conceptual understanding of the movement system

material, with indicators that have been adjusted based on learning objectives and validated by experts and tested for validity and reliability before use; (2) a closed questionnaire of 40 items in the form of a questionnaire with a Likert scale, which is used to measure students' conceptual understanding and mobility of movement, with yes or no answer alternatives; and (3) documentation in the form of data collection on the assignments of class IX IPA 3 students as supporting data that is analyzed qualitatively to strengthen and emphasize the findings of the other instruments. The third instrument has been designed to be suitable for use in research by considering the accuracy of indicator measurements as well as the clarity of the form and number of measuring instruments.

The instrument was previously validated by experts and tested for validity and reliability before use. The conceptual understanding indicators measured were as follows: (1) identifying the bones that form the human skeleton, (2) classifying the types of joints and their movements, (3) describing the structure and function of muscles, (4) explaining the mechanism of muscle contraction, (5) analyzing disorders and diseases of the locomotor system, and (6) applying locomotor system concepts to solve real-life problems. This instrument was validated by two material experts and one evaluation expert, with an average validity score of 3.75 (very valid category) based on a 4-point scale. The reliability test using the KR-20 formula produced a coefficient of 0.82 (high reliability category). These results indicate that this instrument is feasible and consistent for measuring students' conceptual understanding and mobility.

Procedures

This research procedure was conducted through four main development stages based on the 4D model: definition, design, development, and dissemination. In the definition stage, a series of analyses were conducted, including an initial analysis to identify learning tasks in the behavioral systems teaching materials through observation and distribution of a pre-questionnaire to 11th-grade science students at SMAN 2 Binjai. Next, a student analysis was conducted to understand student characteristics, abilities, motivations, and learning experiences. In the task analysis, the main tasks to be mastered were identified based on Core Competencies (KI) and Core Competencies (KD). This stage also included a concept analysis to systematically define a behavioral systems concept map, formulate achievement indicators, create a problem framework, and analyze learning objectives to determine the teaching materials to be included in the booklet.

In the design stage, behavioral systems teaching materials were developed for 11th-grade science students in the odd semester. The teaching materials were developed with consideration for their complexity and visualization needs. Editing was carried out systematically and attractively using the Canva application, and the completed booklet was easily understood by students. Next, a standardized pre-test and post-test consisting of 20 multiple-choice questions were designed to measure conceptual understanding before and after the use of the booklet. During the development phase, the designed media was validated by media experts, material experts, and educational practitioners, and modified based on the feedback provided. Small group trials and limited field trials were conducted to obtain feedback from teachers and students. Finally, during the dissemination phase, an effectiveness test was conducted on the use of the developed booklet media. The study population was 11th-grade students of SMAN 2 Binjai to evaluate the effectiveness of the product in improving conceptual understanding of the movement system material.

Data Analysis

Data analysis in this study used a quantitative approach with the aim of knowing the effectiveness of digital booklet media based on PjBL (Project-Based Learning) in improving the

learning outcomes of students in class XI SMA Negeri 2 Binjai. The effectiveness of learning is measured through the comparison of learning outcomes before and after the use of media, namely, using pretest and posttest scores.

The pretest and posttest scores obtained by students will be analyzed using the N-Gain formula to determine the magnitude of the increase in understanding after treatment. The N-Gain test is a test to calculate the difference between pretest and posttest scores, which indicates how much the ability of students improves after participating in learning. The calculation of N-Gain is done using the following formula (Fathurohman et al., 2023).

$$N - Gain = \frac{Posttest\ Score - Pretest\ Score}{Maximal\ Score - Pretest\ Score}$$

The N-Gain value for each student is then calculated and averaged to get the class N-Gain value. The result of the average N-Gain is an indicator of the increase in learning outcomes after using the media. The interpretation of the N-gain value is presented in Table 1 (Musyafak et al., 2024).

Table 1. Criteria N – gain

Criteria	N – Gain Score
High	$g > 0,7$
Medium	$0,3 < g \leq 0,7$
Low	$g < 0,3$

Based on Table 1, the N-gain value criteria are categorized into three categories, namely low, medium, and high. If the N - gain value is greater than 0.7 then it is included in the high category, this indicates that the booklet is very effective in improving student understanding, if the N - gain value is between 0.3 and 0.7 then it is classified as a medium category which means there is a significant increase, and if the N - Gain value is below 0.3 then it is included in the low category, which indicates that the increase in student learning outcomes is still low even after using the booklet. This also shows that booklets are not effective (Wahab et al., 2021).

In addition to measuring students' conceptual understanding, this study also measured students' mobility through a questionnaire administered after learning using Project-Based Learning (PjBL) booklets. The questionnaire consisted of 20 statements with yes or no options. Yes, answers were given a score of 1, while no answers were given a score of 0. The total score for each student was calculated and then converted into a percentage. The average percentage of all students was used to determine the Student Movement category based on the following criteria: Very Effective (81–100%), Effective (61–80%), Less Effective (41–60%), and Ineffective (≤40%).

This analysis complements the N-Gain results, providing a more comprehensive understanding of the effectiveness of the media both in improving conceptual understanding and in encouraging student engagement during learning.

RESULTS

The effectiveness of the Project-Based Learning (PjBL) booklet learning media was evaluated through a test instrument that measured students' conceptual understanding before (pre-test) and after (post-test) using the media. The analysis of the pre-test and post-test results was conducted using the N-Gain formula to determine the increase in students' conceptual understanding.

Table 2 shows the pre-test and post-test scores, N-Gain scores of each student, and their categories based on the criteria in Table 1.

Table 2. N-Gain of each studentTest Result

No	Student Names	Pretest	Postest	N-Gain	Criteria
1	Student 1	75	95	0,80	High
2	Student 2	85	100	1,00	High
3	Student 3	65	85	0,57	Medium
4	Student 4	45	80	0,64	Medium
5	Student 5	35	80	0,69	Medium
6	Student 6	60	85	0,63	Medium
7	Student 7	40	75	0,58	Medium
8	Student 8	85	100	1,00	High
9	Student 9	65	85	0,57	Medium
10	Student 10	70	95	0,83	High
11	Student 11	35	70	0,54	Medium
12	Student 12	65	90	0,71	High
13	Student 13	50	90	0,80	High
14	Student 14	40	85	0,75	High
15	Student 15	60	90	0,75	High
16	Student 16	75	95	0,80	High
17	Student 17	50	85	0,70	Medium
18	Student 18	65	95	0,86	High
19	Student 19	40	80	0,67	Medium
20	Student 20	65	85	0,57	Medium
21	Student 21	55	85	0,67	Medium
22	Student 22	60	90	0,75	High
23	Student 23	55	90	0,78	High
24	Student 24	60	95	0,88	High
25	Student 25	45	80	0,64	Medium

Table 3 shows the average N-Gain scores of all students. In addition to conceptual understanding, the effectiveness of the Project-Based Learning (PjBL) booklet was also evaluated using a student movement questionnaire. The responses obtained from the questionnaire were analyzed descriptively to determine the categories of student mobility. Table 4 presents the results of the student movement questionnaire analysis.

Table 3. Average N-Gain Scores

Average Value of N - Gain	Category
0,73	Medium

Table 4. Student Movement Questionnaire Result

Category	Number of Students	Percentage (%)
Very Effective	14	56%
Effective	7	28%
Less Effective	3	12%
Ineffective	1	4%

DISCUSSION

This study aims to develop and test the effectiveness of learning media in the form of a Project-Based Learning (PjBL) guidebook in improving learning outcomes, conceptual understanding, and student mobility in motion system material in grade XI at SMAN 2 Binjai. The developed media has been verified by experts and declared suitable for use in terms of content, visual design, readability, and integration with PjBL syntax. The findings show that this guidebook is not only academically relevant, but also practical and interesting to support the learning process.

The effectiveness of this guidebook is demonstrated by learning outcomes with an average N-Gain of 0.73 (high category), which proves a significant improvement in students' cognitive abilities. The designed project activities, such as drawing the body skeleton, making digital posters, and writing essays, encourage students to connect conceptual knowledge with real experiences, making learning more meaningful. In terms of concept understanding, an average score of 80% (effective category) was obtained, indicating that the PjBL-based guidebook was able to help students understand the relationship between bones, muscles, and joints more comprehensively. Meanwhile, the average mobility achievement score of 82% (very effective category) shows that students not only understand the theory but are also able to practice physical skills in accordance with the musculoskeletal system material.

These findings are consistent with previous studies. Hoiroh (2020) showed that electronic books on fungal material have high validity (score of 3.94), practicality (97.5%), and effectiveness (N-Gain 0.75). Fauziyah (2017) also reported that the biology pocketbook developed was valid (score of 3.5) and effective (average of 3.6 and 3.1), with positive responses from teachers and students at Madrasah Aliyah Alauddin Pao-Pao and MAN 1 Makassar. Meanwhile, Paramita et al. (2018) found that the medicinal plant inventory pocketbook obtained an average validity score of 3.46 thanks to the clarity of its content, format, and language. Therefore, this study not only reinforces previous findings on the effectiveness of pocketbooks in biology learning but also expands on them by adding mobility as a measure of success.

The effectiveness of this medium can be explained through constructivism theory, which emphasizes the importance of direct student involvement in knowledge formation. PjBL (Project-Based Learning)-based guidebooks provide meaningful learning experiences through project activities that require students to actively connect theory with practice. This explains the high level of conceptual understanding and significant improvement in learning outcomes, as well as the achievement of optimal mobility. Therefore, this medium has been proven to encourage students to learn more actively, creatively, and contextually.

Apart from the academic aspect, this research is also relevant to the concept of the student movement. In the context of education, the student movement can be understood as the active involvement of students in the learning process that emphasizes autonomy, intellectual independence, and collaboration. Through PjBL-based guidebooks, students are trained to work together, generate ideas, and connect concepts with real-world practices, thereby forming an intellectual movement in the classroom that reflects a progressive spirit. Therefore, guidebooks not only improve students' academic achievement but also foster awareness of their role as part of a more active and meaningful learning movement.

CONCLUSION

The findings of this study demonstrate that the use of digital booklet media based on Project-Based Learning (PjBL) in the human locomotor system material effectively enhances conceptual understanding, learning outcomes, and students' movement mobility in Grade XI of SMAN 2 Binjai. The average N-Gain score of 0.73 places this media in the moderately effective category, indicating a significant improvement after the learning process. This effectiveness not

only strengthens cognitive aspects but also fosters practical skills through contextual project activities, thereby creating a more meaningful and applicable learning experience. The novelty of this research lies in the development of a digital booklet that simultaneously measures conceptual understanding and movement mobility, thus providing a new contribution to the implementation of digital media in biology education at the secondary school level. Based on these results, the PjBL-based digital booklet can be recommended as an innovative learning medium, and future research is suggested to apply this media to other biology topics with a broader sample to ensure more comprehensive generalization of its effectiveness.

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