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Research Article

Development of the BINA Android Learning App for Basic Movements in Big Ball Games

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Abstract:

Background: Physical Education learning in elementary schools remains predominantly reliant on conventional textbook-based instruction, limiting students' conceptual understanding and mastery of fundamental movement skills in big ball games. This gap highlights the need for interactive, technology-integrated learning media that align with students' developmental characteristics and promote active engagement. **Purpose:** This study aimed to develop an Android-based learning application, BINA (Belajar Interaktif Nalar Aktif), and to systematically evaluate its validity and practicality as a digital learning medium for basic movement skills. **Methods:** This study employed a Research and Development (R&D) approach using the Plomp model, consisting of preliminary research, prototyping, and assessment phases. The participants included three expert validators (material, media, and language experts), three Physical Education teachers, and 30 sixth-grade students. Data were collected through structured validation and practicality questionnaires and analyzed using descriptive quantitative techniques based on a four-point Likert scale. **Results:** The findings indicate that the BINA application achieved maximum validity (M = 4.00) across all dimensions. Material validation scores reached 4.00 for content quality, applicability, and visual presentation. Media validation also showed perfect scores (4.00) for content quality, interface design, and instructional layout. Language validation demonstrated consistent results (4.00) across all indicators, including clarity, communicativeness, interactivity, developmental appropriateness, and linguistic accuracy. In terms of practicality, teacher evaluations yielded optimal results (M = 4.00) across all aspects, including content suitability, media design, language, usability, and instructional effectiveness. Student evaluations further confirmed high practicality, with an overall mean score of M = 3.73, comprising content suitability (3.75), media display (3.68), language (3.70), usability (3.73), and perceived learning effectiveness (3.77). **Conclusion:** The BINA application is proven to be a valid and practical digital learning medium that effectively supports motor skill development in elementary Physical Education. By integrating multimedia and mobile learning.

Keywords*:* Android Application BINA, Basic Movement Skills, Big Ball Games

Introduction

Background of the study: Education plays a fundamental role in developing human potential and advancing national progress by fostering cognitive, physical, social, and emotional competencies in learners. Within the Indonesian educational context, education is defined as a conscious and systematic effort to create learning environments that enable students to actively develop their full potential across multiple domains (Revana et al., 2025). However, despite ongoing educational reforms, significant challenges remain in improving learning quality, particularly in ensuring effective instructional delivery, meaningful student engagement, and optimal utilization of learning media.

In recent years, rapid technological advancement has transformed educational practices,

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leading to increased integration of mobile learning and digital media across educational contexts. In the context of Physical Education, the integration of digital technologies has become increasingly important in enhancing instructional effectiveness, improving accessibility, and supporting student learning. Previous studies have shown that the integration of digital technology in Physical Education supports more effective instructional delivery, enhances learning flexibility, and improves student engagement and learning experiences (Nopembri et al., 2022; Syahlan et al., 2024).

Physical Education plays a crucial role in promoting physical literacy, motor competence, and lifelong physical activity participation among children. Motor competence, defined as the ability to perform a range of fundamental movement skills, is a critical component of children's physical development and serves as a foundation for participation in sports and physical activities (Robinson et al., 2015). Fundamental movement skills, including locomotor, non-locomotor, and manipulative skills such as running, jumping, throwing, and catching, are essential for supporting children's physical development and overall health (Barnett, Stodden, et al., 2016; Logan et al., 2012). Research has consistently demonstrated that motor competence is positively associated with physical activity participation, physical fitness, and long-term health outcomes (Barnett, Lai, et al., 2016). Furthermore, the development of motor competence during childhood is essential for promoting physical literacy, which encompasses the motivation, confidence, physical competence, and knowledge necessary for lifelong engagement in physical activity (Caldwell et al., 2020).

Literature review: Research indicates that one of the key determinants of learning effectiveness is the quality of instructional design and the use of appropriate learning media that can facilitate active engagement and meaningful knowledge construction (Hattie, 2008). Learning media function not merely as instructional aids but as cognitive tools that support information processing, improve comprehension, and enhance learner motivation through structured and meaningful content presentation (Mayer, 2014).

The integration of multimedia learning principles has been shown to significantly enhance learning effectiveness by facilitating dual-channel processing, reducing cognitive load, and promoting deeper understanding through the integration of visual and verbal representations (Moreno & Mayer, 2007). Multimedia-based instructional environments enable learners to actively engage with content, thereby improving retention, conceptual understanding, and motivation. These benefits are particularly relevant in subjects that require procedural and motor skill learning, such as Physical Education, where visual demonstration plays a critical role in facilitating skill acquisition.

Mobile learning, defined as the use of portable digital devices to facilitate learning anytime and anywhere, has demonstrated significant positive effects on student learning performance, engagement, and motivation (Sung et al., 2016). Systematic reviews and meta-analyses have confirmed that mobile learning environments provide flexible, accessible, and personalized learning experiences that enhance student achievement across educational levels (Crompton et al., 2017; Hwang & Tsai, 2011). Mobile devices enable interactive learning experiences that support self-paced learning, immediate feedback, and multimodal content delivery, thereby facilitating more effective and engaging learning environments (Sung et al., 2016).

Digital media, including mobile applications, instructional videos, and interactive learning platforms, have been shown to improve student engagement, facilitate skill acquisition, and support pedagogical innovation in Physical Education settings (Casey et al., 2016; Price et al., 2024). Digital technologies enable teachers to shift from traditional teacher-centered instruction

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toward more student-centered learning approaches that promote active participation and independent learning (Casey & Jones, 2012). Furthermore, interactive digital environments and game-based learning have been shown to increase motivation, engagement, and learning outcomes in Physical Education by providing immersive and meaningful learning experiences (Papastergiou, 2009). Educational games and digital learning platforms have also been shown to improve students' understanding of sports techniques and enhance skill mastery through interactive and visual learning environments (Mukti et al., 2025).

Mobile learning applications specifically designed for Physical Education have demonstrated significant potential in improving motor skill learning by providing visual demonstrations, interactive feedback, and opportunities for repeated practice (Yang et al., 2020). Mobile applications also enable students to learn independently outside classroom settings, thereby extending learning opportunities beyond traditional instructional environments (Pálička et al., 2016). In addition, the use of digital media in Physical Education has been associated with improved instructional efficiency, enhanced student motivation, and increased engagement in learning activities (Can et al., 2025).

Technology-based learning media also play an important role in improving students' learning experiences by providing interactive, visual, and engaging instructional content (Tantri et al., 2023). Digital learning applications have been shown to improve students' responsibility, participation, and learning outcomes in Physical Education (Traindini et al., 2024). The use of digital learning media also increases students' active learning time and promotes meaningful learning experiences (Sutarjo & Hadiwinarto, 2022). Additionally, digital learning media and structured instructional management strategies have been shown to improve learning effectiveness, technical skill acquisition, and student performance in Physical Education (Tifal, 2023). The development of digital learning media in Physical Education has also been shown to improve accessibility, flexibility, and instructional effectiveness. Android-based learning applications enable students to access learning materials anytime and anywhere, facilitating independent learning and repeated practice (Anty, 2023). Interactive digital media also support inclusive learning environments and improve learning accessibility for diverse. Furthermore, digital learning media improve instructional efficiency and support effective teaching practices in Physical Education (Syahlan et al., 2024).

Gap analysis: Despite the recognized importance of Physical Education and digital learning integration, many schools continue to rely heavily on traditional teaching methods and printed instructional materials. This limitation reduces instructional effectiveness, student engagement, and opportunities for meaningful motor learning experiences. Research in Indonesia has shown that Physical Education learning often faces challenges related to limited learning media, inadequate use of technology, and insufficient integration of digital tools in instructional practice (Mustafa, 2022; Syafruddin, 2023). The lack of interactive and engaging learning media limits students' ability to understand movement concepts and develop motor skills effectively (Nur Budi Nugraha, 2024; Rahman, 2025).

Despite the growing body of research supporting the effectiveness of digital learning media, there remains a lack of context-specific mobile learning applications designed specifically to support motor skill learning in big ball games at the elementary school level. Most existing digital learning tools focus primarily on cognitive learning rather than motor skill development, highlighting the need for specialized digital learning media that support both cognitive and motor learning processes.

Rationale of the study: The integration of digital media and mobile learning applications has been

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identified as an effective solution for improving Physical Education learning. Research has demonstrated that digital learning media improve learning effectiveness, increase student motivation, and enhance learning outcomes in Physical Education (Doni et al., 2022; Ritonga et al., 2025). Interactive learning media, including Android-based applications, have been shown to improve student engagement, facilitate skill acquisition, and enhance learning effectiveness (Fatah & Apriani, 2025; Ngandhika et al., 2018). Furthermore, digital learning media enable teachers to deliver instructional content more effectively while supporting student-centered learning approaches

Purpose of the study: This study aims to develop an Android-based learning application called BINA (Belajar Interaktif Nalar Aktif) as a learning medium for basic motor skills in big-ball games for elementary school students at Public Elementary School 187 Pekanbaru. Specifically, this study focuses on designing the BINA application as an Android-based instructional medium for basic motor skills in big ball games and examining its validity and practicality to ensure its feasibility and effectiveness for use in Physical Education learning.

Material & Methods

Research Design: This study employed a Research and Development (R&D) design to produce an Android-based learning media named BINA (Belajar Interaktif Nalar Aktif) for basic movement materials in big ball games for elementary school students. The development process adopted the Plomp development model, which emphasizes systematic planning, iterative development, and continuous evaluation through three main phases: preliminary research, development or prototyping, and assessment (Arfendi et al., 2023; Plomp & Nieveen, 2013).

The preliminary research phase was conducted to identify learning needs, analyze student characteristics, and examine instructional problems encountered in Physical Education, particularly those related to the mastery of basic motor skills in big-ball games, through interviews and classroom observations. The development or prototyping phase involved the structured design, development, and refinement of the BINA application based on theoretical frameworks, curriculum demands, and user needs. Subsequently, the assessment phase focused on evaluating the quality of the developed product in terms of validity and practicality through expert validation and field testing in real learning settings using structured questionnaires (Sugama et al, 2020).

The Plomp model was selected because it is well-suited for the development of technology-based educational products that require systematic design procedures, iterative improvement, and contextual feasibility. Therefore, this study was directed toward producing a learning medium that is valid and practical, without examining its effectiveness on student learning outcomes.

Participant: The population of this study consisted of Physical Education teachers and sixth-grade students at Public Elementary School 187 Pekanbaru, Tampan District, Pekanbaru City, Riau Province. Participants were selected using purposive sampling, as this technique allows the selection of individuals who are directly involved in and relevant to the implementation of the BINA application in Physical Education learning.

During the validation stage, three expert validators were involved, comprising one material expert, one media expert, and one linguist. These experts were tasked with evaluating the accuracy of the learning content, the quality of media design, and the appropriateness of language use within the application using structured questionnaire instruments.

At the practicality testing stage, the participants consisted of three Physical Education teachers and thirty sixth-grade students. The teachers assessed the application from an instructional

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and pedagogical perspective, while the students evaluated the practicality of the application based on their direct learning experiences using Likert-scale questionnaires (Febtriko et al, 2018).

Instrument: Data collection in this study employed multiple instruments that were aligned with the stages of the Plomp development model to ensure comprehensive data coverage. Semi-structured interviews were conducted during the preliminary research phase to explore learning needs, instructional challenges, and expectations of Physical Education teachers and sixth-grade students regarding basic movement learning in big ball games.

Classroom observations were carried out to document authentic learning conditions, instructional strategies, and the implementation of Physical Education learning, particularly in relation to students' basic motor skill development. In addition, structured questionnaires were used during both the validation and practicality testing stages. Validation questionnaires were administered to expert validators to assess content suitability, media design quality, and language clarity, while practicality questionnaires were distributed to Physical Education teachers and students to measure ease of use, attractiveness, and perceived usefulness of the BINA application in the learning process.

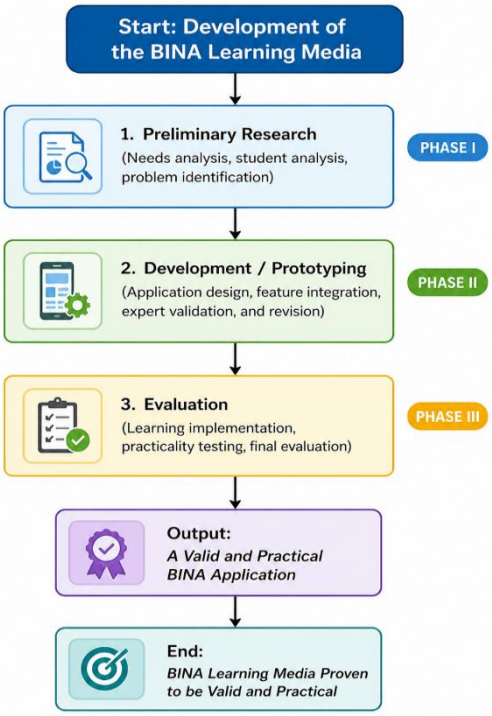

Figure 1. BINA Application research flow

All questionnaire items were constructed based on established quality indicators of digital learning media and rated using a four-point Likert scale, ranging from 1 (very poor) to 4 (very good). Furthermore, a physical activity quiz embedded within the BINA application functioned as an internal evaluation tool to assess students' understanding of basic movement concepts.

Procedures: During the development and assessment stages, questionnaires were used to collect data on both validity and practicality. In the validation phase, questionnaires were distributed to three expert validators, consisting of one material expert, one media expert, and one linguist. These experts assessed the application based on content accuracy, media design, and linguistic appropriateness, respectively. The questionnaire items were arranged according to recognized quality indicators of digital learning media and utilized a Likert scale ranging from 1 to 4. The results from this phase provided evidence of the content and construct validity of the BINA application.

In the practicality testing stage, questionnaires were administered to two PJOK teachers and thirty-sixth-grade students who used the BINA application during classroom learning. The instrument measured their responses related to the ease of use, attractiveness, and usefulness of the application in the PJOK learning context. Responses were then analyzed quantitatively using descriptive statistics in SPSS, yielding objective, measurable results regarding the application's practicality. Additionally, a physical activity quiz embedded within the application functioned as an internal evaluation tool to measure students' understanding of basic movement concepts. The quiz consisted of multiple-choice questions designed to be engaging and appropriate for the developmental stage of elementary school students. The quiz results not only served as formative assessments for teachers but also enhanced student motivation and involvement in the learning

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process. This instrument supported the measurement of the application's educational effectiveness and reinforced its role as an interactive and reflective learning tool.

Table 1. Research and Development Matrix of the BINA Application

Title	Data Sources	Research and Development Method	Research Flow
Development of the Android-Based BINA Application as a Learning Media for Fundamental Movements in Big Ball Games	• Two sixth-grade PJOK teachers • Thirty sixth-grade students • Curriculum documents • Three expert validators (material, media, language)	This study used a Research and Development (R&D) method with the Plomp model, which consists of three main phases: 1. Preliminary Research: Conducting needs analysis through interviews, classroom observations, and curriculum document review. 2. Prototyping: Designing the BINA application based on needs analysis results, then validating it with material, media, and language experts. The product is revised based on expert feedback. 3. Assessment: Conducting limited trials with teachers and students to evaluate practicality aspects such as attractiveness, ease of use, and usefulness.	4. Needs Analysis: Interviews with teachers and students, classroom observations, and curriculum analysis to identify problems related to fundamental movement materials in big ball games. 5. Application Design: Developing storyboards, interfaces, and learning content featuring videos, illustrations, and interactive quizzes. 6. Expert Validation: Validation by material experts (completeness, curriculum relevance, concept accuracy), media experts (interface, navigation, design quality), and language experts (clarity, communicativeness, suitability to student development). 7. Product Revision: Refining the application based on expert feedback and comments. 8. Limited Trial: Involving two PJOK teachers and thirty sixth-grade students using practicality questionnaires and in-app quizzes. 9. Data Analysis: Employing descriptive quantitative analysis with a Likert scale (1–4) using SPSS software. 10. Final Product: An Android-based BINA application that is valid and practical for use as a PJOK learning media on fundamental movements in big ball games.

Analysis plan: Data analysis in this study employed descriptive quantitative and qualitative approaches to ensure objective and contextual interpretation of the findings. Quantitative data obtained from validation and practicality questionnaires were analyzed using SPSS (Statistical

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Package for the Social Sciences) software by calculating mean scores for each assessment aspect based on the four-point Likert scale.

An average score within the range of $3.00 \leq \bar{x} \leq 4.00$ indicated that the developed media met the criteria for validity or practicality. Descriptive quantitative analysis was used to present the collected data in the form of mean values and percentage distributions (Sugiyono, 2019). Qualitative data derived from interviews, classroom observations, and expert suggestions were analyzed descriptively to support product revision and to provide deeper contextual explanations for the quantitative results.

This analysis plan ensured that the evaluation of the BINA application was conducted systematically, objectively, and rigorously, thereby providing strong evidence regarding its feasibility and usability as an interactive learning media in Physical Education instruction.

Descriptive quantitative analysis was considered appropriate because the primary objective of this study was to evaluate the validity and practicality of the developed learning media, rather than to measure its effectiveness on learning outcomes. This approach is consistent with research and development studies that focus on product feasibility and usability in authentic educational settings. Future studies are recommended to examine the effectiveness of the application on students' learning outcomes using experimental or quasi-experimental designs.

Results

This research developed the BINA application as an Android-based learning medium to support Physical Education learning on basic movement in big ball games at the elementary school level. The results are presented according to the stages of the Plomp model, which include: (1) Preliminary Research, (2) Prototyping Phase, and (3) Assessment Phase.

1. Expert Validation Results

   Validation involved three experts: material, media, and language experts. Each expert assessed the BINA application using a Likert scale (1–4) on relevant aspects. The average score from each aspect was used to determine whether the application met the criteria for validity. Although the validation results showed maximum scores across all assessed aspects, expert reviewers provided several qualitative suggestions for improvement. These included minor refinements to visual consistency, clarification of instructional wording, and enhancement of navigation flow to improve user experience. All suggestions were incorporated into the revised version of the BINA application before the practicality testing phase. These suggestions did not influence the validity status of the product but were aimed at improving clarity and user experience.

   a. The material expert assessed three aspects: content quality, applicability, and visual appearance. Based on SPSS analysis, the average score was in the valid range.

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Table 2. Material Expert Validation Results
(SPSS data processing results, Material Expert Validation, 2025)

Aspect	Average Score	Criteria
Content Quality	4,00	Valid
Applicability of Material	4,00	Valid
Visual Display	4,00	Valid
Average	**4,00**	**Valid**

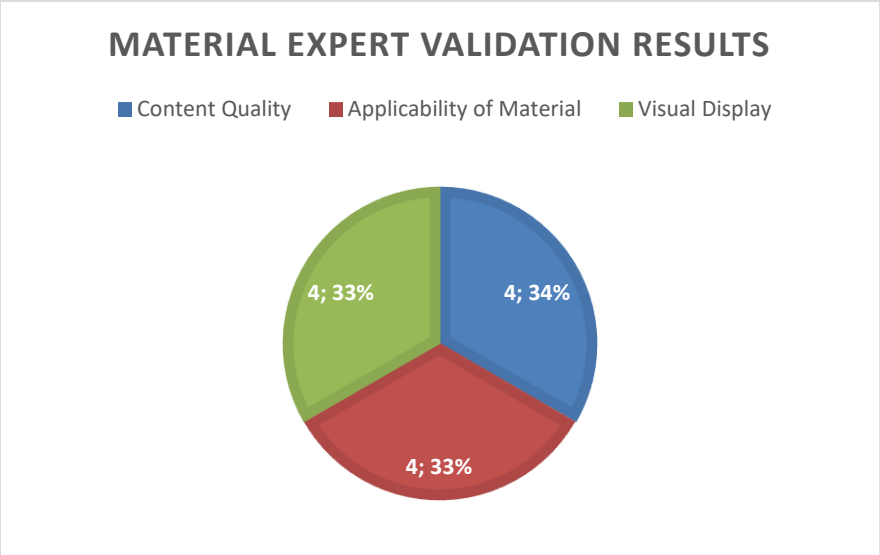

Figure 2. Material Expert Validation Results

b. Media Expert Validation
The media expert assessed media quality, interface appearance, and content design. All scores met the validity criteria.

Table 3. Media Expert Validation Results
(SPSS data processing results, Media Expert Validation, 2025)

Aspect	Average Score	Criteria
Content Quality	4,00	Valid
Interface Appearance	4,00	Valid
Content Design	4,00	Valid
Average	**4,00**	**Valid**

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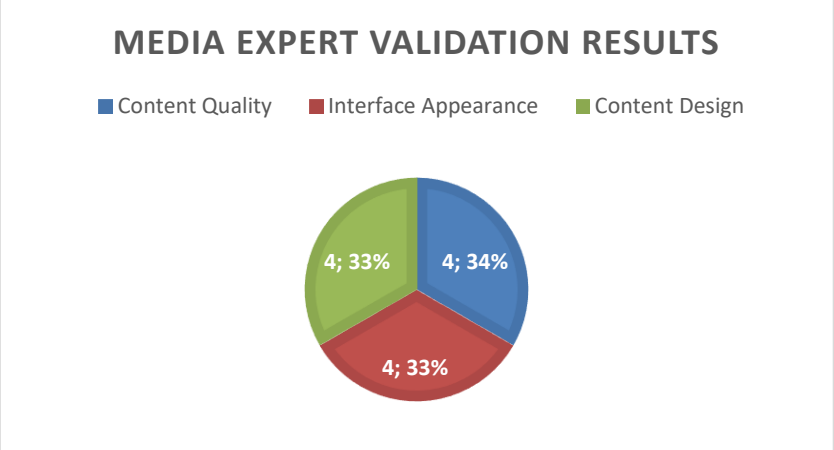

Figure 3. Media Expert Validation Results

c. Language Expert Validation
Language experts assessed effectiveness, communicativeness, interactivity, language accuracy, and suitability for students.

Table 4. Language Expert Validation Results
(SPSS data processing results, Language Expert Validation, 2025)

Aspect	Average Score	Criteria
Sentence Effectiveness and Directness	4,00	Valid
Communicativeness	4,00	Valid
Interactivity and Motivation	4,00	Valid
Appropriate for Student Development	4,00	Valid
Language Accuracy and Symbols	4,00	Valid
Average	**4,00**	**Valid**

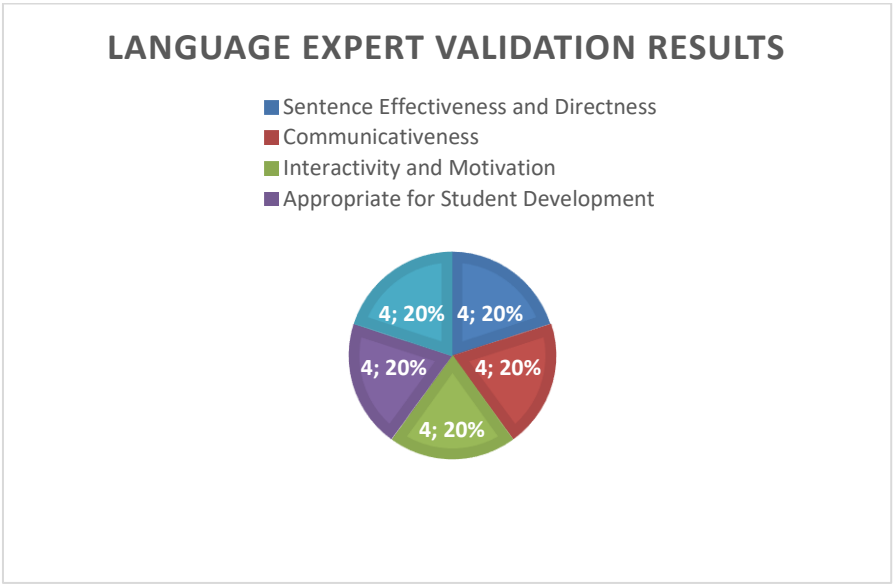

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Figure 4. Language Expert Validation Results

2. Practicality Test Results
   After revisions, the practicality of the application was tested with two respondent groups: Physical Education teachers and Grade VI students. The practicality aspects include attractiveness, ease of use, and usability.
   a. Teachers' Assessment
      Three Physical Education teachers assessed the application based on 12 statements.

Table 5. Practicality Results by Teachers
(SPSS data processing results, Practicality by Teachers, 2025)

Aspect	Average Score	Criteria
Content Suitability	4,00	Practical
Media/Display Suitability	4,00	Practical
Linguistics	4,00	Practical
Practicality	4,00	Practical
Effectiveness and Impact of Learning	4,00	Practical
Average	**4,00**	Practical

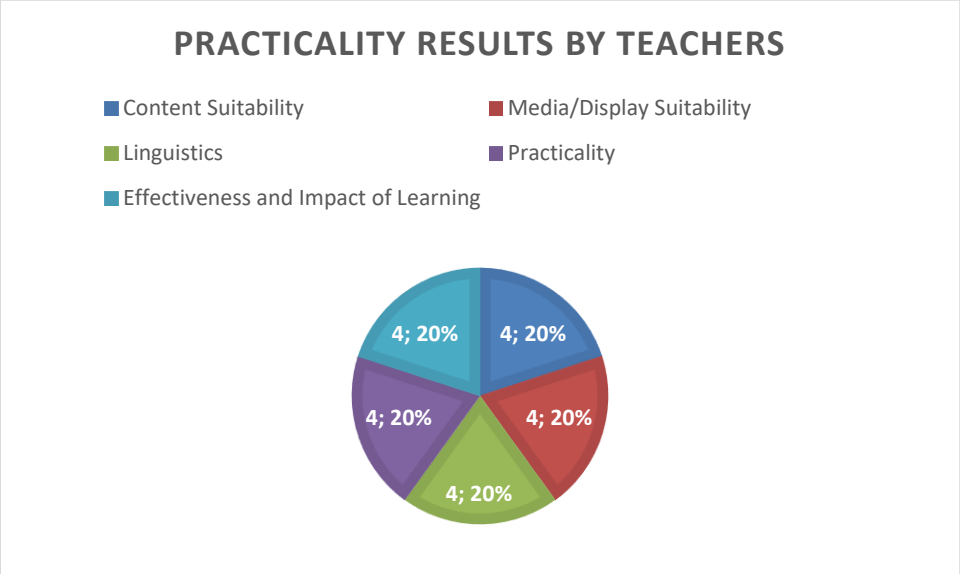

Figure 5. Practicality Results by Teachers

   b. Students' Assessment
      Thirty Grade VI students assessed the BINA application after using it directly.

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Table 6 Practicality Results by Students
(SPSS data processing results, Practicality by Students, 2025)

Aspect	Average Score	Criteria
Content Suitability	3,75	Practical
Media/Display Suitability	3,68	Practical
Linguistics	3,70	Practical
Practicality	3,73	Practical
Effectiveness and Impact of Learning	3,77	Practical
Average	**3,73**	**Practical**

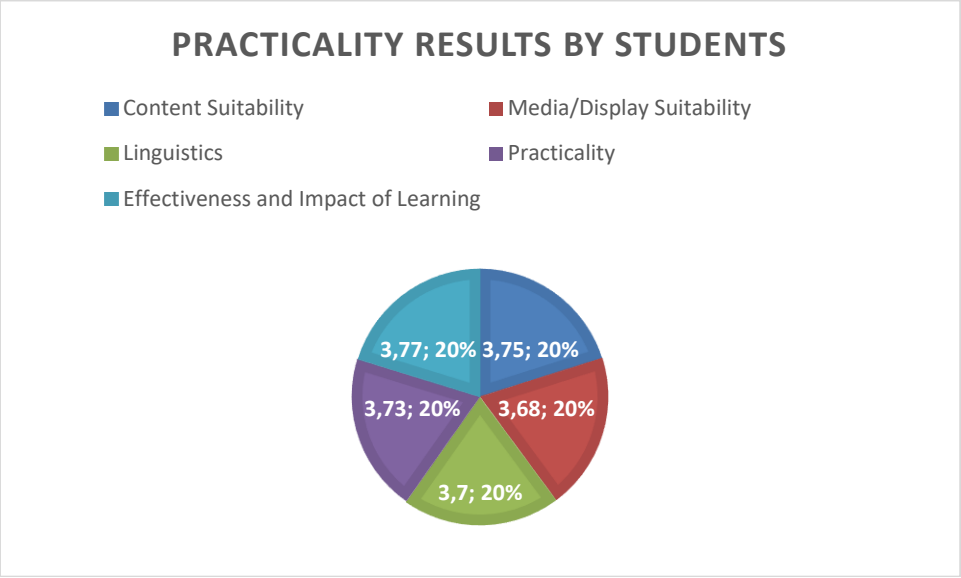

Figure 6. Practicality Results by Students

3. Interpretation of Results

The analysis indicates that the BINA application is highly valid and practical. This supports Mayer's theory (2005) which emphasizes the effectiveness of multimedia learning through the integration of text, images, and videos. Experts stated that the BINA application content aligns with the curriculum, is complete, and uses communicative language. This aligns with Arsyad's view (in Septiani, 2023) that good media must be both interesting and suitable for learners' characteristics.

From a practicality perspective, the application attracted students' interest and helped teachers deliver basic movement material more efficiently. This supports Akbar (2021), who stated that practicality in media is shown through its ease of use and usefulness. The interactive features of BINA-such as videos and quizzes-enhance the learning experience, allowing students to practice and self-assess their understanding. In conclusion, the BINA application meets the need for innovative, modern, and student-friendly Physical Education learning media. It can be used independently or as a companion tool in classroom instruction.

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Discussion: The findings of this study confirm that the BINA application fulfills the criteria of a valid and practical Android-based learning medium for Physical Education at the elementary school level. The convergence of quantitative validation scores and qualitative user feedback indicates that the application is not only technically feasible but also pedagogically appropriate. The structured organization of learning materials, supported by multimedia elements such as motion videos and visual illustrations, facilitates students' understanding of basic movement concepts that are central to big ball games.

From a theoretical perspective, the effectiveness of the BINA application can be explained through the Cognitive Theory of Multimedia Learning, which posits that meaningful learning occurs when information is presented through well-integrated visual and verbal channels. In the context of Physical Education, where learning outcomes are closely related to motor skills and movement execution, the availability of visual demonstrations becomes particularly critical. The application successfully bridges the gap between abstract explanation and concrete movement practice, a limitation often encountered in conventional Physical Education instruction.

Moreover, the positive responses from teachers and students suggest that the application supports instructional efficiency and learner engagement. Teachers benefit from a more systematic delivery of material, while students experience greater autonomy and enjoyment in learning. These outcomes reinforce the role of digital learning media as a complementary tool in Physical Education instruction, especially in schools with limited access to diverse teaching resources.

Implications: The results of this study have several practical implications for Physical Education learning at the elementary school level. First, the BINA application can serve as an effective alternative or supplement to traditional teaching methods, particularly for delivering basic movement material that requires visual modeling. Second, the application supports integrating technology into Physical Education, aligning instruction with contemporary educational demands for digital literacy and student-centered learning.

For schools such as Public Elementary School 187 Pekanbaru, which may face constraints in instructional media and facilities, the BINA application offers a scalable and accessible solution. Its use can enhance the quality of Physical Education learning without requiring extensive additional infrastructure, provided that basic Android devices are available.

Research Contribution: This study contributes to the field of Physical Education learning media development by providing empirical evidence on the validity and practicality of an Android-based application specifically designed for Physical Education. Unlike many digital learning tools that focus on cognitive subjects, this research highlights the potential of mobile applications to support motor learning and physical literacy at the elementary school level.

In addition, the study enriches the body of literature on multimedia-based learning in Physical Education by demonstrating how theoretical principles, such as multimedia learning theory, can be operationalized in practical instructional media. The BINA application also represents a contextualized innovation that responds directly to the needs of Physical Education teachers and students in public elementary schools.

Limitations: Despite its positive findings, this study has several limitations. The practicality test involved a relatively small sample size of 30 students from a single school, which limits the generalizability of the results. In addition, data collection through questionnaires administered to elementary school students has certain limitations, as students differ in their ability to comprehend written statements. This condition may affect the accuracy of their understanding of questionnaire items, thereby influencing the completeness and reliability of the responses obtained. These

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limitations indicate that the findings should be interpreted with caution, particularly when considering broader implementation across different educational contexts.
Suggestions: Future research is recommended to involve larger and more diverse samples across multiple schools and regions to strengthen the external validity of the findings. Further development of the BINA application should also consider incorporating offline functionality to address connectivity issues and reduce barriers related to digital inequality.

Conclusions

This study concludes that the BINA application is a valid and practical Android-based interactive learning medium that effectively supports Physical Education learning, particularly in teaching basic movement skills in big ball games at Public Elementary School 187 Pekanbaru. Expert evaluations in terms of content, media design, and language indicate that the application meets established validity standards. The findings also highlight the broader implication that well-designed digital learning media can enhance the quality of basic education, including subjects that rely heavily on physical activity and motor skills. Compared to conventional teaching methods, the BINA application provides an effective alternative that promotes active learning and increases students' interest in Physical Education. In conclusion, the development of the BINA application demonstrates the significant potential of digital innovation to enrich Physical Education learning at the elementary school level. Future research is recommended to expand the application to other Physical Education topics, implement it across a wider range of schools, and examine its long-term effectiveness.

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Author Contribution Statement

FA conceived and designed the study, developed the BINA application, conducted data collection and analysis, and drafted the manuscript. AV and AP supervised the research process, provided methodological guidance, validated the research framework, and critically revised the manuscript. KA, MI, and RL served as examiners, providing academic evaluation, constructive feedback, and recommendations to improve the quality of the research and manuscript.

AI Disclosure Statement

In the preparation of this manuscript, the author utilized artificial intelligence (AI) technology, specifically ChatGPT (OpenAI, GPT-5), in a limited and controlled manner. The use of AI was strictly confined to technical assistance in structuring academic sentences, language editing, and improving the quality of English grammar to ensure compliance with scholarly writing standards. All research ideas, problem formulation, methodological design, data analysis, interpretation of

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results, and the drawing of conclusions are entirely the intellectual work and responsibility of the author. AI played no role in scientific decision-making, the determination of academic content, or validation of the research findings.

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