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The effectiveness of biomechanical technology-based sports training models in improving elementary school students' motor skills

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Abstract. Fundamental motor skills are an essential foundation for the holistic development of elementary school students, influencing their health, self-confidence, and academic success. This study aims to develop and test the effectiveness of a Biomechanics-Integrated Technology-Based Sports Training Model (VAB-F) to improve elementary school students' long jump motor skills. This study employed a multidisciplinary design, utilising mixed methods and a sequential explanatory approach, with a quantitative stage in the form of a quasi-experiment (*pre-test post-test control group design*) involving 60 fifth-grade students from SDK Magepanda. The sample was randomly divided into an experimental group (n = 30) and a control group (n = 30). Motor skills were assessed using a validated long jump technique quality assessment rubric, which was supplemented with biomechanical analysis through the Kinovea application and a Wearable *Activity Tracker*. The qualitative stage consisted of interviews with 6 students and 2 teachers. The results showed that the experimental group experienced a statistically significant increase in skill scores (an average increase of 29.70 points) compared to the control group (an average increase of 9.60 points), with the t-test results indicating a highly significant difference ($t(58) = 15.23$, $p < 0.05$). The qualitative results showed that the visual feedback technology encouraged independence, motivation, and intuition of student movement efficiency. It was concluded that the VAB-F training model was significantly more effective than traditional methods in improving the long jump motor skills of elementary school students.

Introduction

The development of basic motor skills in elementary school-aged children (SD) is an important foundation for the physical, cognitive, and social development of elementary school-aged children (SD) (Aliriad et al., 2025; Li & Siriphan, 2023). Mastery of skills such as running, jumping, throwing, catching, and kicking is not only essential for participation in a variety of physical activities and sports, but is also positively correlated with long-term health, self-confidence, and academic success (Çolak et al. 2024; Garbeloto & Pereira, 2024; Gumilar et al. 2023). The elementary school age period is considered the "golden age" for the development of motor skills, where appropriate intervention can have a significant positive impact on a child's movement patterns into adulthood (Beddoes & Sazama, 2024; Hernawan et al., 2024). Therefore, physical education in elementary schools plays a crucial role in facilitating optimal motor development for each student (Aksović et al., 2021).

However, realities on the ground show that physical education learning often faces various challenges. Traditional teaching methods, which tend to be uniform, often result in a lack of personalised feedback and limited facilities and teaching aids, leading to less than optimal development of students' motor skills (Cobb et al., 2013; Donno et al., 2025; Liang, 2025). Many students exhibit inefficient or biomechanically incorrect movement patterns, which not only hinder performance but also increase the risk of injury (Hu & Huang, 2025). Teachers often struggle to provide accurate and timely corrections to large classes, particularly in identifying detailed movement errors that are not readily apparent to the naked eye. Initial observations revealed that more than half of the students, 56%, had unsatisfactory running times. This low performance was identified as being related to weaknesses in running speed and body movement segmentation during activity. This finding was further strengthened by the results of a primary study analysing 1000-meter running performance, where the average time for students was 7.49 minutes (Baktiyaningsih & Irawan, 2023; Sa et al., 2024). When these results were classified based on physical fitness assessment standards, the conditions were found to be alarming. Not a single student was found to be able to achieve the "fairly good," "good," or "very good" categories. Instead, the absolute majority of students (92%) fell into the "very poor" category, with the remaining 8% in the "poor" category. Therefore, it can be concluded that the analysis of the students' running movements generally fell into the "very poor" category, indicating a fundamental and widespread problem with their motor skills.

In this era of digitalisation, technology offers great opportunities to revolutionise the learning process, including in the context of physical education (Cui et al., 2023; Lang et al., 2025). Various devices and applications, ranging from *smartphones equipped* with high-resolution cameras and motion analysis software, such as Kinovea, are now increasingly accessible (Au et al., 2024). The use of this technology enables the visualisation of movements in real-time slow motion, side-by-side comparisons between student movements and ideal models, and simple biomechanical measurements such as joint angles or motion trajectories (Baktiyaningsih & Irawan, 2023; Sa et al., 2024). The potential of this technology lies in providing objective and specific feedback that surpasses the capabilities of a teacher's manual observation, enabling students to identify and understand their own mistakes independently (Misjel et al., 2022; Szabo-Alexi et al., 2021).

Although the potential of technology in sports learning has been extensively researched, most of the focus remains on high-achieving athletes or adult populations. Research specifically integrating technology-based biomechanical analysis into Physical Education learning models to improve elementary school students' motor skills, particularly in Indonesia, remains relatively limited (Azhari & Galih Priyambada, 2025; Baktiyaningsih & Irawan, 2023; Sa et al., 2024). Previous research has often utilised technology solely as a presentation aid or a simple data collection tool, rather than as a core instrument for motion analysis and structured biomechanical feedback. Therefore, there is an urgent need to develop an innovative, effective, and relevant learning model for elementary school students that simultaneously utilises technological advances and the scientific principles of biomechanics (Bendo et al., 2023; Kozin, 2021).

To bridge the gap between theory and practice, this study introduces the Biomechanics-Integrated Technology-Based Sports Training Model (VAB-F) as an innovative solution. This model directly addresses the limited feedback issues of traditional methods by utilising simple technologies such as Kinovea video analysis software and *Wearable Activity Tracker* (Deshmukh et al., 2025; Pantelidou et al., 2025). This approach transforms abstract verbal instructions into concrete, objective visual feedback, allowing students to see their own movement errors on screen in detail through features like slow-motion. This approach allows students to directly observe and understand the fundamental biomechanical principles that influence long jump performance (Bendo et al., 2023; Cao et al., 2025). This process not only accelerates understanding and allows students to make independent corrections (*self-correction*), but also effectively fosters intuitive biomechanical understanding. Students begin to understand the "why" behind efficient movement and connect elements, such as arm swing, to the outcome of a more powerful jump (Ziaiee et al., 2025). This technological element is expected to significantly increase student motivation and engagement, transforming monotonous practice sessions into interactive and enjoyable activities. Thus, the VAB-F model offers a more effective framework, as it makes the motor skill learning process more visible, understandable, and engaging for students.

While the application of technology in sports learning is not an entirely new concept, the novelty of this study lies in its integrative focus and depth of application. Unlike most previous studies, which focus on professional athletes or adult populations, this study explicitly integrates technology-based biomechanical analysis into the learning context of elementary school students in Indonesia, an area that remains rarely explored. Furthermore, previous studies generally utilise technology as a presentation medium or a simple data collection tool, without making it a core component of the motor learning process. This study fills this gap by designing, implementing, and testing a technology-based learning model that places movement analysis at the centre of pedagogical interventions to improve the technique and movement efficiency of early childhood learners. Thus, the study's primary contribution lies in developing a systematic model that transforms technology into an active learning instrument, not merely a tool, but rather a tool that fosters biomechanical understanding and independent learning within the context of elementary physical education.

Based on the background and gaps described, the problem formulation in this study is: How can a technology-based training model that integrates biomechanical analysis be effectively implemented to improve long jump motor skills in elementary school students? In line with this question, this study aims specifically to develop and test the effectiveness of the Biomechanics-Integrated Technology-Based Sports Training Model (VAB-F). The research hypothesis (H_1) proposed is that there is a statistically significant difference in the increase in motor skills between the group of students who received the VAB-F model treatment and the group of students who used the traditional training method, where the VAB-F model is predicted to produce superior improvement.

Method

This research uses Mixed methods (*mixed methods*) with a sequential explanatory design, consisting of two stages. The first stage employs a quantitative approach, followed by the second stage, which utilises a qualitative approach to deepen further the analysis and understanding of the findings from the quantitative stage (Ivankova et al., 2006). This approach enables researchers to combine quantitative and qualitative data in stages, aiming to provide a deeper understanding of the effectiveness of technology-based sports training models integrated with biomechanics in enhancing the motor skills of elementary school students.

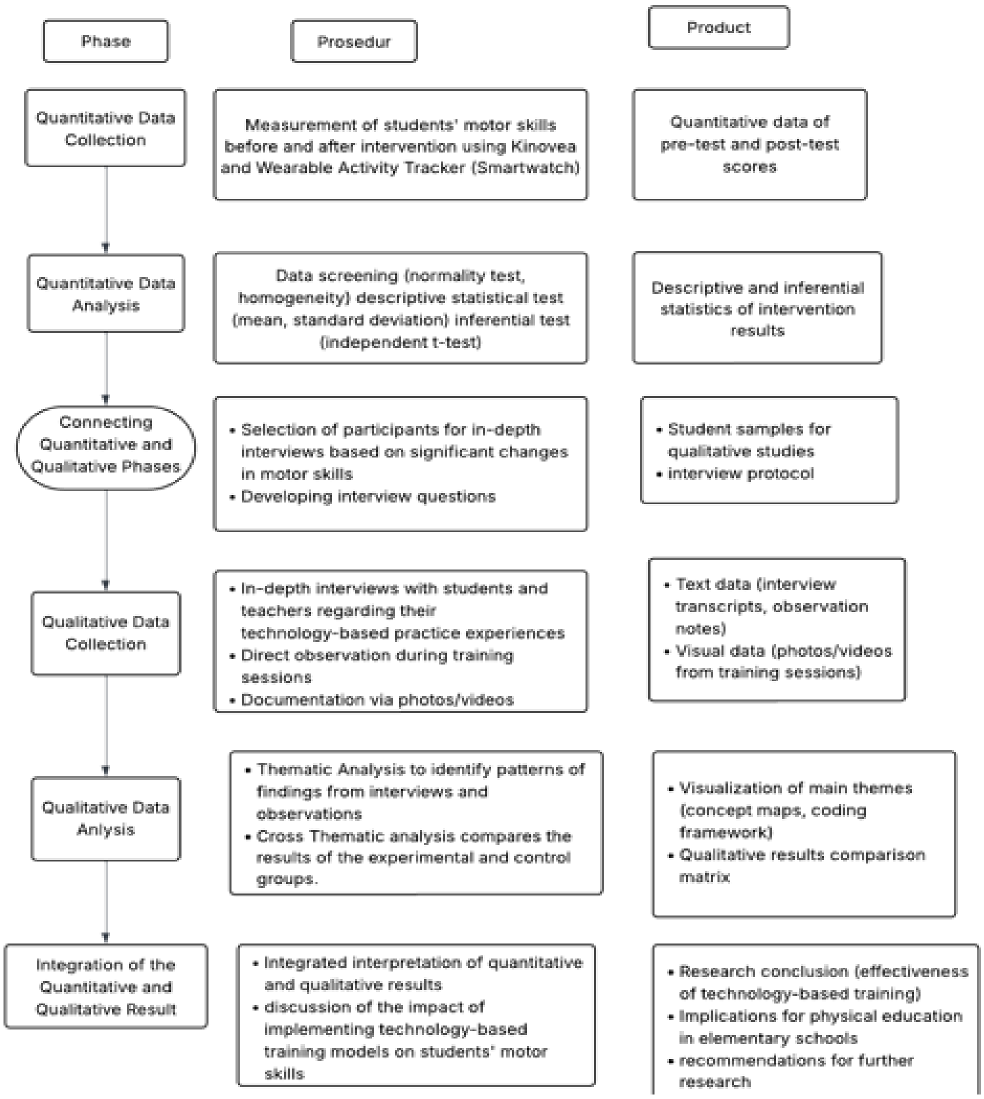

Image 1. Research Flowchart adapted from Ivankova (Ivankova et al., 2006)

Research Procedures

Each stage has a structured procedure aimed at collecting relevant data, analysing it, and obtaining comprehensive results regarding the application of a biomechanically integrated technology-based sports training model.

Stage 1: Quantitative Research Procedures

In the first stage, the research focused on testing the effectiveness of a technology-based sports training model integrated with biomechanics, as well as measuring the improvement in motor skills of elementary school students. The quantitative design used is a quasi-experimental with a pre-test, Post-test, *Control Group Design*. The subjects in this study were 60 fifth-grade elementary school students at Magepanda Elementary School, Sikka Regency, NTT Province, in the 2024/2025 academic year. The sample was divided into an experimental group (n = 30) and a control group (n = 30). In addition, fifth-grade students are at the middle stage of school age, which is ideal for evaluating the effectiveness of technology-based and biomechanical training models, as they have more mature motor control than students in lower grades. The sample selection was conducted using a random sampling technique to form two groups: an experimental group and a control group. The training design of this study differentiated the treatments between the two groups. The experimental group employed a technology-based approach, utilising a Wearable Activity Tracker for monitoring activities and Kinovea for movement analysis. In contrast, the control group followed a traditional training program without the use of any monitoring technology or biomechanical analysis. Quantitative data on students' long jump motor skills were collected using a rubric developed explicitly for this study to assess the quality of long jump technique, supplemented by jump distance measurements. The development of this instrument was based on an in-depth literature review of the biomechanical principles of long jump and the characteristics of elementary school students' motor development (Gumilar et al., 2023; Kozin, 2021; Oktavianus et al., 2025). This rubric was designed to assess each critical phase of long jump technique (run, takeoff, flight, and landing) with clear indicators and a graded rating scale.

Table 1. Long Jump Quality Assessment Rubric

Motion Phase	Rated aspect	Indicator	Score
Prefix	Initial Velocity	Gradually increase towards the support beam.	1-4
	Initial Stability	Straight legs, upright body, looking forward	1-4
	Step length	The final step is slightly shortened in preparation for the push.	1-4
Rejection	Pushing Leg	Tracking the support beam with a full and strong foot	1-4
	Repulsion Angle	Tracking the support beam with a full and strong foot	1-4
	Arm Swing	Both arms are swung forward and upwards strongly	1-4
Floating	Body Position	Position *hang style / hitch-kick* maintained	1-4
	Balance	Doesn't sway in the air	1-4
Landing	Feet Landing	Both legs are stretched forward, heels touching the sand first	1-4
	Body Position	Body Leaning Forward	1-4

The instrument validation process was conducted comprehensively. The rubric's content validity was ensured through assessment by an expert panel consisting of three physical education experts and two sports biomechanics experts. The experts were asked to rate the relevance, clarity, and completeness of each item in the rubric using a Likert scale, and the results were analysed using Content *Validity Index* (CVI). Only items with a CVI score above 0.80 were retained or revised based on expert input (Curtis et al., 2015; Qin et al., 2024). After the instrument was declared content valid, its reliability was rigorously tested. Inter-rater reliability (*inter-rater reliability*) was measured by involving two independent assessors who had been intensively trained. They assessed a series of videos of long jump movements of students who were not included in the research sample. Inter-rater consistency was assessed using Cohen's Kappa Coefficient, yielding an excellent level of agreement ($\varkappa$ > 0.80), which ensured objectivity and consistency in scoring (Fitri et al., 2022). Thus, this validated and reliability-tested rubric can be used accurately to measure the quality of students' long jump technique.

Table 2. Results of the Content Validity Test of the Long Jump Technique Quality Assessment Rubric by the Expert Panel

Rated aspect	Number of Experts	Number of Experts Who Stated It as Very Relevant	CVI	Information
Prefix				
Initial Velocity	5	4	1.00	Valid
Initial Stability	5	5	0.80	Valid

Rated aspect	Number of Experts	Number of Experts Who Stated It as Very Relevant	CVI	Information
Step Length	5	5	1.00	Valid
Rejection				
Pushing Leg	5	5	1.00	Valid
Repulsion Angle	5	4	0.80	Valid
Arm Swing	5	4	0.80	Valid
Floating				
Body position	5	4	0.80	Valid
Balance	5	4	0.80	Valid
Landing				
Feet Landing	5	4	0.80	Valid
Body Position	5	4	0.80	Valid
CVI Rate-Rate			0.86	Valid

In this study, in addition to measuring long jump motor skills using a movement quality assessment rubric, researchers also conducted biomechanical analysis to evaluate takeoff speed, takeoff angle, body position during takeoff, balance during landing, and arm swing speed. The tools used for the biomechanical analysis included the Kinovea app for video movement analysis and a wearable activity tracker for monitoring speed and pressure distribution.

Quantitative data analysis in this study was conducted using SPSS software version 26. The analysis process consists of two main stages: descriptive statistics and inferential statistics. Descriptive statistics are used to present initial data in the form of averages (*mean*) and standard deviation (*standard deviation*) from the pre-test and post-test of both groups. Before conducting a hypothesis test, a prerequisite analysis test is first performed to ensure the data meet the parametric statistical assumptions. The prerequisite tests performed include a normality test for data distribution using the Shapiro-Wilk Test and a homogeneity of variance test using *Levene's Test.* After the data is proven to be normally distributed and have homogeneous variance, an inferential statistical analysis is carried out using the Independent Sample t-Test (*Independent Samples t-Test*). This test is used to test the research hypothesis by comparing the difference in improvement scores (*gain score*) between the experimental group and the control group at a significance level of $\alpha = 0.05$.

Stage 2. Qualitative Research Procedures

After the quantitative analysis was completed, the research entered its second phase, utilising a qualitative approach to gain a deeper understanding of students' and teachers' experiences related to the implemented training models. At this stage, participant selection was conducted purposively. Participants consisted of student representatives from the experimental and control groups, selected based on specific criteria such as their level of active engagement during the program and perceived significant changes. In addition to students, interviews will also involve the PE teachers responsible for implementing the training to gain professional perspectives on the effectiveness and challenges of each model.

The qualitative data collection process will utilise two primary methods: interviews and observations. Semi-structured interviews will serve as the primary instrument to explore students' and teachers' perceptions, challenges, and perceived impacts related to the use of technology in training and its impact on motor skill improvement. To complement the interview data, direct field observations will be conducted during training sessions. This method aims to obtain contextual data and validate the information gathered from the interviews, particularly regarding the practical application of technology and biomechanical principles in training.

Table 3. VAB-F Model Interview Guidelines

Participants	**Question**
Student	How did it feel the first time you saw your own movements on screen?
	Is it easier to understand a teacher's explanation or watch a video yourself? Why?
	What did you learn about your body movement that made your jumps better?
	Does your jump feel different when you do the correct movement?
Teacher	How would you compare the effectiveness of Kinovea visual feedback with conventional verbal instructions?
	Are students quicker in understanding and correcting their mistakes?
	How does this model assist you in teaching the principles of efficient movement to students?
	Do you see students moving from simply imitating to understanding "why" a movement is effective?
	How does the level of enthusiasm and participation of students in this group compare to a regular class?
	Are students becoming more proactive in asking questions and seeking feedback?

Data analysis

The collected quantitative data will be analysed using descriptive statistical techniques (Mean and Standard Deviation) and inferential tests (two independent sample t-tests) to determine the differences between the experimental and control groups. This test aims to determine whether there is a significant improvement in students' motor skills after the implementation of the technology-based training model. Interview and observation data will be analysed using thematic analysis to identify key themes related to participants' experiences. This analysis aims to understand the factors that influence the success or obstacles in implementing the technology-based training model.

Results and Discussion

Quantitative Descriptive Analysis and Classical Assumption Testing

Quantitative data analysis began with the presentation of descriptive statistics to provide an overview of the long jump skill scores in both groups before and after treatment. Prerequisite analysis tests, including normality and homogeneity tests, were also conducted to ensure the data were suitable for parametric analysis. The results of the prerequisite analysis tests are presented in Table 4.

Table 4. Results of the Prerequisite Test for Normality and Homogeneity of Variance Gain Score

Prerequisite Test	Group	Statistical Value	df	Mean (p-value)	Interpretation
Normality Test (Shapiro-Wilk)	Experiment	0.971	30	0.288	Data Normal
	Control	0.965	30	0.194	Data Normal

Prerequisite Test	Group	Statistical Value	df	Mean (p-value)	Interpretation
Homogeneity Test (Levene's Test)	Intergroup	1.157	58	0.286	Homogeneous Variant

Based on the prerequisite test results in Table 4, the significance values of the normality tests (Shapiro–Wilk) for the experimental group and the control group were 0.288 and 0.194, respectively, both of which were greater than 0.05. This indicates that the gain score data is usually distributed. In addition, the results of the homogeneity of variance test (Levene's Test) showed a significance value of $0.286 > 0.05$; thus, it can be concluded that the variance between groups is homogeneous. Thus, the data meet the requirements for parametric testing.

Table 5. Statistical Description of Long Jump Skill Scores Before and After Treatment

Treatment Group	Measurement Level	Number of Students (N)	Average Score ($\bar{x}$)	Standard Deviation (SD)
Experiment (VAB-F Training Model)	Pre-test (Before)	30	45.50	5.20
	Post-test (After)	30	75.20	4.80
	Gain Score		+29.70	
Control (Traditional Training Method)	Pre-test (Before)	30	45.80	5.10
	Post-test (After)	30	55.40	4.90
	Gain Score		+9.60	

Based on the table, it is evident that the average pre-test scores for the experimental group ($\bar{x}$ = 45.50, SD = 5.20) and the control group ($\bar{x}$ = 45.80, SD = 5.10) were relatively equal. The t-test results on the scores pre-test confirmed that there was no statistically significant difference between the two groups before treatment ($p > 0.05$). This indicates that the randomisation process successfully created two groups with comparable initial abilities.

After the intervention, there was an increase in scores in both groups. However, a much more substantial increase was observed in the experimental group, whose average score post-test reached $\bar{x}$ = 75.20 (SD = 4.80). In contrast, the control group only achieved an average score of $\bar{x}$ = 55.40 (SD = 4.90). The difference between the post-test and *pre-test* (*gain score*) indicates that the experimental group achieved an average increase of 29.70 points, whereas the control group increased by only 9.60 points. Next, a prerequisite analysis test was conducted on the data *gain score*. The results of the normality test (for example, using the Shapiro-Wilk test) and the homogeneity of variance test using Levene's Test show that the data from both groups are normally distributed and have homogeneous variance. Thus, the data meet the assumptions for conducting an independent sample t-test (*Independent Samples t-Test*).

The results of the inferential analysis show that there are statistically significant differences in gain score between the two groups, with a t-value of 15.23 at 58 degrees of freedom (df), or $t(58) = 15.23$. The significance value (p-value) obtained is 0.000, which is smaller than the specified significance level ($\alpha = 0.05$). Because the p-value <0.05, the null hypothesis (H_0), which states that there is no difference in the effect of the treatment, is rejected, and the alternative hypothesis (H_1) is accepted. Based on the results of the data analysis, it can be concluded that there is strong statistical evidence to suggest that the application of the Biomechanics Integrated Technology-Based Sports Training Model (VAB-F) is significantly more effective in improving long jump skills in elementary school students compared to traditional training methods.

To provide a deeper understanding of the improvements in long jump technique achieved by students, the following presents a comparison of motor skill improvements and biomechanical data between the experimental and control groups. This data includes measurements of various aspects of long jump technique, such as run-up speed, take-off angle, body position during takeoff, and balance and arm swing. This comparison aims to illustrate how the use of biomechanical analysis-based technology in a sports training model can significantly improve the technical and biomechanical aspects of the long jump movement. The following table shows apparent differences between the two groups based on these measurement results.

Table 6. Comparison of Improvement in Long Jump Technique and Biomechanical Parameters between the Experimental and Control Groups

Aspect	Experimental Group (Pre-test)	Experimental Group (Post-test)	Control Group (Pre-test)	Control Group (Post-test)	Experimental Improvement	Increased Control
Initial Velocity (m/s)	4.3	5.8	4.2	4.4	+1.5	+0.2
Repulsion Angle (°)	40°	45°	41°	42°	+5°	+1°
Body Position (°) while Hovering	15°	25°	16°	17°	+10°	+1°
Balance (Pressure Distribution)	60% left / 40% right	50% left / 50% right	55% left / 45% right	60% left / 40% right	More balanced	A little more balanced
Arm Swing Speed (m/s)	2.0	3.5	2.2	2.3	+1.5	+0.1
Initial Velocity	2.3	3.8	2.4	2.6	+1.5	+0.2
Step Length (m)	2.2	3.7	2.3	2.4	+1.5	+0.1
Arm Swing	2.0	3.8	2.1	2.3	+1.8	+0.2

Qualitative Data Results

To explain why the experimental group showed significantly superior improvement. In-depth, semi-structured interviews were conducted with six students from the experimental group and two physical education teachers involved, as well as direct observations during training sessions. Thematic analysis of interview transcript data and field notes revealed three main themes that explain the success of the VAB-F model.

Theme 1: "Seeing Your Own Mistakes": The Power of Visual Feedback

All interviewed students from the experimental group highlighted the experience of "seeing themselves on screen" as the most influential factor. Before the intervention, students only received abstract verbal instructions. With Kinovea, they could concretely see the difference between their movements and those of the model. One student stated:

*"My teacher used to say, 'The jump has to be right,' but I did not understand what he meant. After watching the video on my laptop, I realised my body was not rotating. When I slowed down the video, it was very clear."*The sports teacher also confirmed this. According to him, visualization*side-by-side*Kinovea cuts down on the time typically spent on repetitive verbal explanations. Students learn faster and can make independent corrections (*self-correction*).

Theme 2: From "Just Jumping" to "Powerful Jumping": Growing Biomechanical Awareness

Although students did not learn the term "biomechanics," interviews revealed that they began to develop an intuitive understanding of movement efficiency. They began to connect elements of movement (such as starting speed, leg push strength, and arm swing) with the results of a further leap. A student named Rian explained: "*I used to think that the long jump was all about running as fast as you could and then jumping. It turns out that you need the right footing and be strong, and swing your arms forward to lift your body. It feels different; you jump further.*" This is supported by observational data, where students in the final weeks of the intervention appeared to be more focused on the overall body movement process, from start to landing, rather than just on the final result of the jump.

Theme 3: "Like Playing a Game": Increasing Motivation and Engagement

Technology elements, including data display from the Wearable Activity Tracker and video analysis, significantly increased student motivation. The practice process no longer felt like a monotonous task, but rather an engaging and interactive activity. One student even described it as a game: *"It's fun, sir! It is like playing a game. Every time I finish jumping, I am curious to see the video again to see if I did it right. It makes me excited to keep trying until the movements are similar to the example."* Teachers also reported higher levels of participation and enthusiasm in the experimental group compared to classes using conventional methods. Students became more proactive in asking questions and seeking feedback.

The qualitative phase of this study was conducted to explore in depth *how and why* the biomechanics-integrated technology-based training model (VAB-F) effectively improved students' motor skills. Semi-structured interviews and direct observations were used to capture the experiences of students and teachers during the implementation of the model. Thematic analysis was applied to identify recurring patterns and generate conceptual meanings from participants' narratives. The analysis revealed several dominant themes that represent the reflective learning process facilitated by the integration of video analysis (Kinovea) and wearable activity tracking. These themes illustrate the transformation of students' learning behaviours from passive performance imitation to active, reflective, and autonomous skill improvement. The comparison of qualitative findings is summarised in the following table.

Table 7. Comparison of Qualitative Findings

Theme	Description of Findings	Supporting Evidence (Interview & Observation)	Interpretation/ Meaning
Visual Self-Awareness: Seeing and Correcting Movement	Students developed the ability to recognise movement errors after seeing their performance through slow-motion video. They became more independent in identifying what needed improvement.	*"After watching the video, I realised my body didn't twist properly. When slowed down, it became clear"*. Observation: Students repeated actions without teacher instruction after reviewing the video.	Technology-based visual feedback enhances self-regulated learning by fostering self-awareness and autonomy in movement correction.
Emergent Biomechanical Understanding:	Students began to understand the relationship	*"If I step strongly and swing my arms, I can jump farther."* Observation:	Reflects embodied cognition, where learners connect

Theme	Description of Findings	Supporting Evidence (Interview & Observation)	Interpretation/ Meaning
Intuitive Grasp of Movement Principles	between body mechanics (take-off, arm swing, balance) and performance results. Their attention shifted from "how far they jump" to "how they move."	Students verbalised and demonstrated biomechanical components correctly during subsequent trials.	physical sensations with conceptual understanding of biomechanics.
Motivation and Engagement Through Technology	Students found the learning process enjoyable and game-like due to the use of real-time video feedback and wearable devices. Teachers observed higher enthusiasm and participation.	*"It's fun, like playing a game. I want to keep watching the video and try again."* Teacher note: Increased excitement and persistence during practice.	Technological elements act as motivational catalysts, stimulating intrinsic motivation and sustained engagement in physical learning.
Reflective Learning Outcome: Autonomous Motor Skill Mastery	The integration of feedback, awareness, and motivation led to improved motor performance and enhanced reflective thinking. Students practised independently and corrected mistakes without external guidance.	Observed post-intervention behaviour: Students took the initiative to evaluate and refine their movement using video playback.	Indicates reflective and autonomous learning, the outcome of the VAB-F model's qualitative impact.

Based on the quantitative and qualitative data analysis conducted, several important findings can be discussed further:

Improving Long Jump Motor Skills: The Impact of Technology and Biomechanics

The results of the statistical analysis showed a very significant difference between the experimental group using the VAB-F model and the control group using the traditional method. Simply put, this means that the success of the experimental group was not due to chance. The increase in the average score in the experimental group (+29.70 points), which was almost three times higher than the control group (+9.60 points), is strong statistical evidence that the VAB-F model is significantly more effective in improving the motor skills of elementary school students in the long jump. The success of the randomisation process was confirmed at the beginning of the study (pre-test, both groups are equal), further strengthening the conclusion that the difference in final results is truly due to the treatment given.

These findings align with the theory that technology use in physical education can facilitate more effective and structured learning. Several previous studies have demonstrated that technology, particularly video- and sensor-based technology, facilitates students' understanding of complex movements, providing more accurate and rapid feedback than verbal instructions alone (Baktiyaningsih & Irawan, 2023; Sa et al., 2024; Citrawan et al., 2024). Furthermore, the fundamental motor skills theory proposed by Li & Siriphan (2023) states that physical skill mastery in children, especially those of elementary school age, is strongly influenced by learning techniques that involve visual components and structured feedback. In this study, the use of applications such as Kinovea allowed students to observe their errors and correct them more independently. This proves that the use of technology in biomechanics-based sports instruction can accelerate the process of technique improvement. The significant difference in motor skill improvement between the experimental and control groups confirms that technology-based training models integrated with biomechanical analysis are more effective than traditional training. This finding is consistent with those of Cobb et al. (2013), who demonstrated that traditional learning methods relying on verbal instructions tend to be less effective in improving movement technique, particularly in large group contexts where technical errors are challenging to detect and correct quickly. In contrast, the use of technology provides immediate feedback, allowing for rapid and effective technique improvement.

Improving Students' Understanding of Biomechanics

One interesting finding from this study is that, despite not receiving a formal explanation of biomechanics, students began to develop an intuitive understanding of the biomechanical principles underlying the long jump movement. Students understood that factors such as takeoff speed, leg push-off force, and arm swing significantly influence their jump distance. This understanding aligns with the theory of Sport Biomechanics, which emphasises the importance of body coordination and efficient movement strategies to achieve optimal performance (Gumilar et al., 2023). This finding also supports a study by Çolak et al. (2024), which demonstrated that a deeper understanding of biomechanics in sports movements not only enhances technique but also reduces the risk of injury. With visual feedback from technology like Kinovea, students became more aware of how improvements in technique (such as take-off angle and body position) could affect their jump results. This suggests that by using biomechanics-based technology, students not only imitate movements but also begin to understand why they are executed in a certain way.

The Influence of Technology on Student Motivation and Engagement

One of the major contributions of this technology-based training model is increasing student motivation and engagement in physical education lessons. Interviews with students revealed that technology-supported training became more enjoyable and interactive, almost like a game. This suggests that gamification elements in learning can increase student engagement, which aligns with motivational theories in education that suggest technology use can trigger intrinsic engagement (Misjel et al., 2022; Widana et al., 2023). A study by Cui et al. (2023) also revealed that technology that provides live movement visualisations, such as those used with Kinovea, can increase student motivation to improve their technique continuously. This demonstrates that technology-based learning not only accelerates the process of improving technique but also changes students' perceptions of physical activity, making it more engaging.

Biomechanics Learning and Motor Skill Improvement

Essentially, the results of this study indicate that technology-based biomechanical analysis plays a significant role in enhancing students' motor skills, particularly in sports that require specific techniques, such as the long jump. By providing more objective and detailed feedback, technology enables students to understand the technical aspects of their movements better. This aligns with motor learning theory, which posits that learning involving direct and visual feedback can accelerate the acquisition of motor skills (Hernawan et al., 2024). However, while technology offers significant benefits, it is also important to note that this technology-based approach must be combined with clear instructions and attention to students' psychological aspects. In this regard, the teacher's role remains crucial in guiding students and providing necessary support throughout the learning process.

The primary contribution of this research lies in the development and validation of a systematic learning model for a historically underserved population. While technology in sport has been extensively researched, most studies have focused on elite athletes or adults. Existing research on children often utilises technology superficially, for example, as a presentation tool, rather than as a core instrument for biomechanical feedback. This research fills this gap by demonstrating that simple and accessible technology (such as Kinovea) can be deeply integrated into a Physical Education curriculum to teach complex biomechanical principles to elementary school students intuitively. Its novelty lies in demonstrating that children not only improve their motor skills but also begin to understand the "why" of efficient movement, a shift from mere imitation to conceptual understanding. This study provides strong empirical evidence for motor learning theory, underscoring the crucial role of rapid, accurate, and visual feedback in accelerating skill acquisition. Furthermore, the findings contribute to the sports pedagogy literature by demonstrating that biomechanical principles can be effectively taught at an early age through appropriate technological mediation. The VAB-F model provides a practical, effective, and cost-effective framework for Physical Education teachers. Teachers can utilise commonly owned devices (such as smartphones) to implement video-based feedback, thus providing more personalised attention even in large classes. For curriculum developers, this research provides a basis for designing more modern, engaging, and digital-age Physical Education teaching materials, which not only train physically but also foster a scientific understanding of body movement.

It is important to acknowledge several limitations of this study. First, the generalizability of the findings may be limited because the study was conducted in only one school (SDK Magepanda) with a sample of 60 students. Different student characteristics and school environments may produce varying results. Second, this study focused only on one motor skill, namely the long jump. The effectiveness of the VAB-F model for other, more complex skills (e.g., ball games) has not been tested. Third, this study did not measure the long-term effects (retention) of the skill improvements. Whether the improvements in students' motor skills and biomechanical understanding persist several months after the intervention is completed remains an open question. These limitations can serve as a reference for future research to replicate the study in more diverse populations and different types of motor skills.

Conclusion

Based on the results of the research conducted, it can be concluded that the application of the Integrated Biomechanics-Based Technology Sports Training Model (VAB-F) significantly improves long jump motor skills in elementary school students. The experimental group, which utilised biomechanical analysis-based technology, experienced a significantly greater improvement in long jump skills compared to the control group that followed traditional training methods. This improvement was not only measured in the fundamental technical aspects of the long jump, such as starting speed and take-off angle, but also in biomechanical aspects, including body position during flight and balance during landing.

The use of technology, particularly apps like Kinovea for video analysis and wearable activity trackers for monitoring speed and pressure distribution, provides highly effective visual feedback, allowing students to spot and correct errors in their movements more quickly. This not only improves their technique but also enhances their intuitive understanding of the biomechanical principles underlying the long jump movement.

Furthermore, this technology-based training model can increase student motivation and engagement. Students become more active and engaged in learning through movement, visualisation, and real-time analysis, making the training process more engaging and interactive. This improvement aligns with theories suggesting that the use of technology in physical education can enhance student understanding and skills more efficiently and enjoyably.

From a pedagogical perspective, the application of this model demonstrates that technology not only facilitates more effective learning but also helps teachers provide faster and more accurate feedback, which was previously difficult to achieve with traditional methods. This supports the importance of a technology-based approach in physical education curricula in this digital age.

Overall, this research makes a significant contribution to the development of an innovative learning model that integrates technology and biomechanics in physical education, with the potential to enhance students' motor skills in a more holistic and scientifically informed manner. These findings are expected to encourage changes in teaching practices and provide a scientific basis for the development of more effective physical education curricula in the future.

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Bibliography

Aksović, N., Skrypchenko, I., Bjelica, B., Mohan Singh, R. R., Milanovic, F., Nikolic, D., & Zelenović, M. (2021). The influence of motor skills on the short sprint results. *Pedagogy of Physical Culture and Sports*, *25*(6), 382–387. https://doi.org/10.15561/26649837.2021.0607

Aliriad, H., Da'i, M., Priadana, B. W., Wigantara, M. R., & Arifianto, M. R. (2025). Improving primary school children's motor skills: A physical education approach using circuit games with auditory sequencing. *Edu Sportivo: Indonesian Journal of Physical Education*, *6*(1), 15–29. https://doi.org/10.25299/esijope.2025.vol6(1).19149

Au, W. W., Recchia, F., Fong, D. Y., Wong, S. H. S., Chan, D. K. C., Capio, C. M., Yu, C. C. W., Wong, S. W. S., Sit, C. H. P., Ip, P., Chen, Y. J., Thompson, W. R., & Siu, P. M. (2024). Effect of wearable activity trackers on physical activity in children and adolescents: A systematic review and meta-analysis. *The Lancet Digital Health*, *6*(9), e625–e639.https://doi.org/10.1016/S2589-7500(24)00139-0

Azhari, A. B., & Galih Priyambada. (2025). Biomechanical analysis of shooting techniques using kinovea software in elementary school students. *Journal of Sports Education Students*, *6*(1), 109–120. https://doi.org/10.55081/jumper.v6i1.4265

Baktiyaningsih, L., & Irawan, F. A. (2023). Analysis of the 1000 meter run in elementary school children of bina amal, semarang city: A review of sports biomechanics. *Journal of SPORT (Sport, Physical Education, Organization, Recreation, and Training)*, *7*(1), 137–142. https://doi.org/10.37058/sport.v7i1.6587

Beddoes, Z. E., & Sazama, D. S. (2024). Principal perceptions and applications of professional learning communities: Implications for the future of physical education. *Journal of Teaching in Physical Education*, *43*(1), 1–10. https://doi.org/10.1123/jtpe.2022-0167

Bendo , A. , Agolli , L. , & Kasa , A. (2023). Analysis of biomechanical parameters on il_eo and 1l_ec tests on 10-14 year old players of tirana fc. *International Journal of Human Movement and Sports Sciences*, *11*(3), 564–571. https://doi.org/10.13189/saj.2023.110308

Cao, H., Hua, X., Yang, L., Aoki, K., Shang, S., & Lin, D. (2025). A systematic review of biomechanics of clear aligners by finite element analysis. In *BMC Oral Health* (Vol. 25, Issue 1). BioMed Central Ltd. https://doi.org/10.1186/s12903-025-06295-6

Citrawan, I. W., Widana, I. W., Sumandya, I. W., Widana, I. N. S., Mukminin, A., Arief, H., Razak, R. A., Hadiana, D., & Meter, W. (2024). Special education teachers' ability in literacy and numeracy assessments based on local wisdom. *Jurnal Ilmiah Ilmu Terapan Universitas Jambi*, *8*(1), 145-157. https://doi.org/10.22437/jiituj.v8i1.32608

Cobb, B. R., Urban, J. E., Davenport, E. M., Rowson, S., Duma, S. M., Maldjian, J. A., Whitlow, C. T., Powers, A. K., & Stitzel, J. D. (2013). Head impact exposure in youth football: Elementary school ages 9-12 years and the effect of practice structure. *Annals of Biomedical Engineering*, *41*(12), 2463–2473. https://doi.org/10.1007/s10439-013-0867-6

Çolak, Y., Gur, F., & Ayan, V. (2024). Examining the impact of sports and physical activities on basic motor skills in primary school children. *International Journal of Sport Culture and Science*. https://doi.org/10.14486/IntJSCS.2024.726

Cui, J., Du, H., & Wu, X. (2023). Data analysis of physical recovery and injury prevention in sports teaching based on wearable devices. *Preventive Medicine*, *173*. https://doi.org/10.1016/j.ypmed.2023.107589

Curtis, L. M., Revelle, W., Waite, K., Wilson, E. A. H., Condon, D. M., Bojarski, E., Park, D. C., Baker, D. W., & Wolf, M. S. (2015). Development and validation of the comprehensive health activities scale: A new approach to health literacy measurement. *Journal of Health Communication*, *20*(2), 157–164. https://doi.org/10.1080/10810730.2014.917744

Deshmukh, A. A., Vakil, S., Deshpande, M. S., & Dhote, P. R. (2025). Evaluation of lower extremity range of motion and muscle tightness in individual of age 18–20 years on performance of squat-to-stand and cross-legged sit-to-stand tests: A comparative-analytical study. *Journal of Orthopaedic Reports*, *4*(4). https://doi.org/10.1016/j.jorep.2024.100511

Donno , L. , France , C. , Motta , F. , LoMauro , A. , Gorla , C. , Scaccabarozzi , D. , Tarabini , M. , & Galli , M. (2025). Biomechanical insights into ski mountaineering: Kinematics and muscular activation in uphill movements. *Applied Sciences (Switzerland)*, *15*(3). https://doi.org/10.3390/app15031003

Fitri, R., Reza, M., & Ningrum, M. A. (2022). Learning readiness instrument: A non-test assessment to measure early childhood learning readiness from a neuroscience perspective. *JP2KG AUD (Journal of Early Childhood Education, Care, Health and Nutrition)*, *1*(1), 17–32. https://doi.org/10.26740/jp2kgaud.2020.1.1.17-32

Garbeloto, F., & Pereira, S. (2024). Infographic: Relationship between fundamental movement skills and sports skills. *Brazilian Journal of Motor Behavior*, *18*(1). https://doi.org/10.20338/bjmb.v18i1.441

Gumilar, A., Hakiki, F., Kusuma, B. A., Sumpena, A., Firmansyah, H., Yudiana, Y., & Fajrah Ilsya, M. N. (2023). Identification of basic manipulative movement skills throwing, catching, kicking, and trapping in children aged 15-16 years. *Journal of Physical Education For Secondary Schools*, *3*(1), 199–206. https://doi.org/10.17509/jpess.v3i1.82598

Hernawan, H., Widyawan, D., Mukhtar, M., Nugraha, H., & Haqiyah, A. (2024). Physical activities and sedentary time of students outdoor education and conventional education in primary schools. *International Journal of Disabilities Sports and Health Sciences*, *7*(2), 389–395. https://doi.org/10.33438/ijdshs.1403090

Hu, Z., & Huang, Z. (2025). Biomechanical research on the construction and optimization of youth basketball training system based on the integration of sports and education. *MCB Molecular and Cellular Biomechanics*, *22*(1). https://doi.org/10.62617/mcb797

Ivankova, N. V., Creswell, J. W., & Stick, S. L. (2006). Using mixed-methods sequential explanatory design: from theory to practice. *Field Methods*, *18*(1), 3–20. https://doi.org/10.1177/1525822X05282260

Kozin, S. V. (2021). Biomechanical technology of injury prevention in the training of specialists in physical education and sports. *Health, Sport, Rehabilitation*, *7*(2), 65–76. https://doi.org/10.34142/HSR.2021.07.02.06

Lang, S., Yang, J., Zhang, Y., Li, P., Gou, X., Chen, Y., Li, C., & Zhang, H. (2025). Application of wearable insole sensors in in-place running: Estimating lower limb load using machine learning. *Biosensors*, *15*(2). https://doi.org/10.3390/bios15020083

Li, Y., & Siriphan, C. (2023). Construction of a sensory integration physical education model to improve basic motor skills in primary schools. *International Journal of Sociologies and Anthropologies Science Reviews*, *3*(6), 375–384. https://doi.org/10.60027/ijsasr.2023.3640

Liang, X. (2025). Innovation of college physical education teaching and training mode based on mobile information technology of internet of things from a biomechanical perspective. *MCB Molecular and Cellular Biomechanics*, *22*(1). https://doi.org/10.62617/mcb799

Misjel, N. R., Jabbarb, A. S., Tuama, H. M., & Jabbard, H. S. (2022). Influence of dynamic training on the biomechanics and height of volleyball spike in young players. *SPORT TK - Euro-American Journal of Sports Sciences*, 9. https://doi.org/10.6018/sportk.509461

Oktavianus, I., Gustian, U., & Triansyah, A. (2025). Unveiling current and future trends in the implementation of teaching games for understanding in primary school: A bibliometric analysis. *Physical Education Theory and Methodology*, *25*(1), 191–201. https://doi.org/10.17309/tmfv.2025.1.23

Pantelidou, M., Błach, W., Rydzik, Ł., Ambroży, T., Lockhart, R., Angioi, M., Sokołowski, K., & Malliaropoulos, N. (2025). Video-biomechanical analysis of the shoulder kinematics of impact from sode-tsurikomi-goshi and tsurikomi-goshi judo throws in elite adult judoka. *Applied Sciences (Switzerland)*, *15*(3). https://doi.org/10.3390/app15031152

Qin, L., King Yan Ho, W., Xie, Y., Wang, J., Cheng, L., Liu, Z., Pan, L., & Khoo, S. (2024). The development and validation of a scale to assess perception of physical education among university students in china. *Sage Open*, *14*(1). https://doi.org/10.1177/21582440241228910

Sa, A., Elementary School Teacher, P., & Surabaya State, U. (2024).*Application of biomechanics concepts to improve student learning outcomes in human movement systems learning at elementary school level*.

Szabo-Alexi, P., PocsaI, I., & Szabo-Alexi, M. (2021). Optimizing the assessment of motor skills in 6th grade pupils through multimedia means. *Baltic Journal of Health and Physical Activity*, *13*(Special Issue 1), 87–96. https://doi.org/10.29359/BJHPA.13.Spec.Iss1.08

Widana, I. W., Sumandya, I. W., Citrawan, I. W. (2023). The special education teachers' ability to develop an integrated learning evaluation of Pancasila student profiles based on local wisdom for special needs students in Indonesia. *Kasetsart Journal of Social Sciences, 44*(2), 527–536. https://doi.org/10.34044/j.kjss.2023.44.2.23

Ziaiee, M., Sadeghi, H., Karimi, M. T., & Rafiaei, M. (2025). Assessment of mandibular kinematic variables using a motion analysis system and a regular mobile phone. *Journal of Biomedical Physics and Engineering*, *15*(1), 67–76. https://doi.org/10.31661/jbpe.v0i0.2210-1555