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TGfU-Based Volleyball Learning Model to Improve Student Interest and Outcomes

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Abstract

Study purpose. Despite the recognized benefits of active learning approaches, there remains a limited number of empirically validated learning models specifically designed for volleyball in elementary school settings that effectively address both learning interest and outcomes. This study aims to develop, evaluate the feasibility, and examine the effectiveness of a Teaching Games for Understanding (TGfU)-based volleyball learning model in improving elementary school students' learning interest and outcomes.

Materials and methods. This Research and Development (R&D) study utilized the ADDIE model (Analysis, Design, Development, Implementation, Evaluation). Participants included expert validators, physical education teachers, and elementary school students. Data were gathered through interviews, questionnaires, and assessment rubrics, and analyzed using descriptive and inferential statistics, specifically a paired-samples t-test. The results indicated that the developed model was feasible, with an average score of 93.33% in the small-scale trial and 94.50% in the large-scale trial. The effectiveness test showed a statistically significant improvement between pretest and posttest scores in students' learning interest and volleyball basic skills (underhand passing, overhand passing, and serving), with $p < 0.05$ (paired t-test).

Results. This finding confirms that the TGfU-based volleyball learning model effectively enhances both student engagement and learning outcomes. In conclusion, the developed model is valid, reliable, feasible, and effective for use in elementary school physical education to improve students' interest and learning outcomes.

Conclusions. Based on the presented research abstract, it can be concluded that the developed Teaching Games for Understanding (TGfU)-based volleyball learning model is proven valid, reliable, feasible, and effective for

implementation in physical education in elementary schools. This model is significantly able to increase student learning interest and learning outcomes, especially in basic volleyball skills such as underhand passing, overhand passing, and serving. These findings confirm that the TGfU approach is a valuable pedagogical strategy for increasing student engagement and academic achievement in the context of sports learning.

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Introduction

Physical Education, Sports, and Health (PJOK) plays a fundamental role in fostering students' physical, cognitive, and affective development. In elementary schools, volleyball is one of the most commonly taught sports; however, its instructional implementation often fails to achieve optimal learning outcomes. Traditional teaching approaches tend to emphasize isolated technical drills, such as passing and serving, without integrating them into meaningful game contexts. As a result, students frequently experience boredom, low engagement, and limited understanding of tactical application in real-game situations (Zhang, 2020).

This approach, while aimed at mastering techniques, often leaves students bored, disengaged, and struggling to understand the relevance of these techniques in a game. As a result, active student participation declines, and learning outcomes fall short of their potential. Students may memorize the movements, but lack a clear understanding of when and why they should be used in dynamic game situations. This situation highlights a gap between the holistic aims of the Physical Education curriculum and its implementation in the classroom (López-Ferrer, A., Marco-Ahulló, A., et., 2022). This issue reflects a broader pedagogical limitation, where the focus on technique mastery does not sufficiently support students' decision-making skills, game understanding, and intrinsic motivation. Previous studies have highlighted that conventional approaches in physical education may hinder the development of holistic learning outcomes, particularly in terms of interest and active participation (Fani, R. A., & Sukoco, 2019).

The TGfU approach reverses conventional teaching logic by starting with a modified game, allowing students to immediately grasp the essence of the game while learning contextually relevant techniques. Therefore, research to develop, test the feasibility, and analyze the effectiveness of a TGfU-based volleyball learning model is highly relevant and urgent (Fani, R. A., & Sukoco, 2019). This research is expected to produce a proven pedagogical solution that can address the challenges of low interest and learning outcomes in elementary school students in volleyball learning, as well as provide practical guidance for physical education teachers to create a more effective and enjoyable teaching and learning process (Sgrô, F., Barca, M., et., 2020).

In volleyball, TGFU has been shown to significantly improve overhead passing skills by engaging students in a tactical game structure that enhances their interest and motivation (Sujarwo, S., Suharjana, S., et., 2021). In the context of team offensive sports for children aged 8 to 11, TGFU facilitates autonomous problem-solving through game-based learning, although there is a noted preference for offensive principles in the classroom design (Arfa, M., Akhmad, I., & Nugraha, 2019). The Teaching Games for Understanding (TGfU) model has been proposed as an alternative approach that emphasizes game-based learning, tactical awareness, and student-centered instruction (Manullang & Ngatimin, 2023). Research has demonstrated that TGfU can enhance skill execution, decision-making, and motivation across various sports contexts, including volleyball, basketball, and badminton (Kadhum, M. M., Mohseen, H. S., & Saad, 2020). Furthermore, TGfU encourages contextual learning by engaging students in

modified games, allowing them to understand the "why" and "when" of skill application rather than merely the "how".

However, despite the growing body of literature on TGfU, several important gaps remain. First, most previous studies focus primarily on skill improvement or cognitive aspects, with limited integration of learning interest and multidimensional learning outcomes (cognitive, affective, and psychomotor) in a single framework (Agustini Raaiyatini et al., 2024). Second, there is still a lack of systematic development studies using structured instructional design models such as ADDIE, particularly in the context of elementary school volleyball learning. Third, empirical evidence examining the effectiveness of TGfU-based learning models through development research (R&D) remains limited, especially in Indonesian primary education settings (Suhairi et al., 2023).

The application of TGFU in badminton has been validated as feasible and effective, with the structured game model encouraging creativity and variety in teaching methods (Wianatun et al., 2025). Furthermore, TGFU has been found to improve metacognitive knowledge and regulation, as well as gameplay performance, in physical education settings, suggesting its broader educational benefits beyond mere skill acquisition (Muharram, N. A., & Kurniawan, 2019). Collectively, these studies underscore the versatility and effectiveness of TGFU in enhancing the cognitive and physical dimensions of sport learning across various contexts and age groups. Therefore, this study addresses these gaps by developing and evaluating a TGfU-based volleyball learning model using the ADDIE framework and examining its effectiveness in improving both students' learning interest and learning outcomes.

Materials and methods

This Research and Development (R&D) adopted the ADDIE model, which includes the stages of Analysis, Design, Development, Implementation, and Evaluation. To test the effectiveness of the developed product, a one-group pretest-posttest design was used. The research subjects involved 8 expert validators for the model feasibility assessment, 2 physical education teachers for the small-scale trial, 5 teachers for the large-scale trial, and 23 elementary school students for the effectiveness test. Data collection instruments consisted of interviews for needs analysis, a Likert-scale questionnaire to measure learning interest and model feasibility, and an assessment rubric to evaluate cognitive, affective, and psychomotor learning outcomes. Data analysis involved descriptive statistics for model feasibility and inferential statistics using paired-samples t-test to determine significant differences between pretest and posttest scores on learning interest and basic volleyball skills in Figure 1.

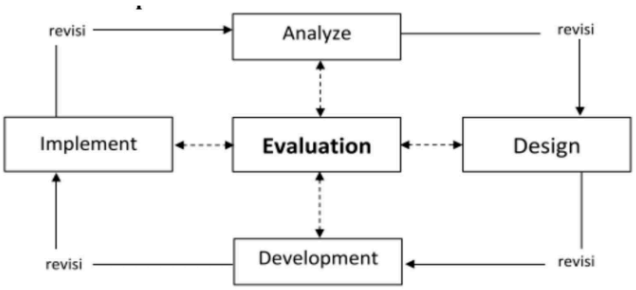

Figure 1. ADDIE Model Stages (Mudjisusatyo et al., 2025)

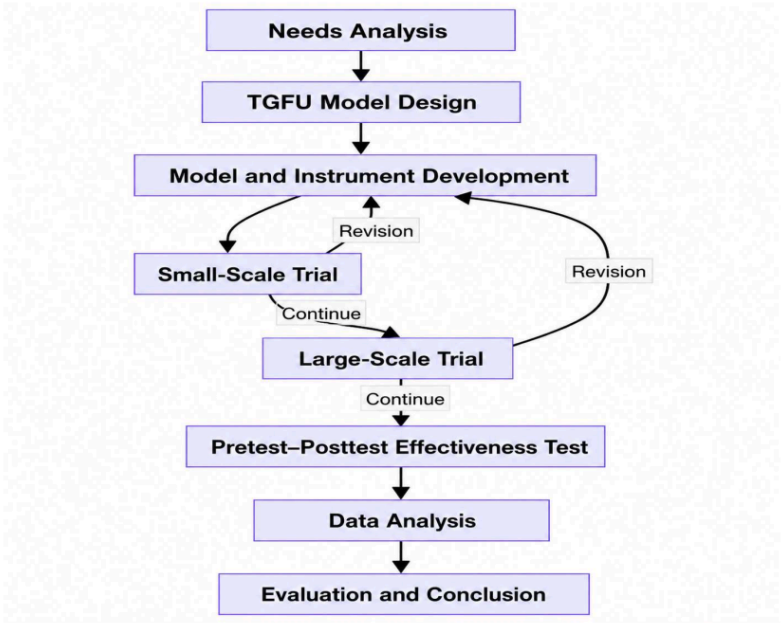

Figure 2. Research flowchart

Study participants

Participants in this study were selected purposively to meet the needs of each stage of the study and consisted of several groups, namely: Expert Validators: This group consisted of 8 validators consisting of material experts (experts in the fields of physical education and volleyball) and media experts (experts in the design and development of learning media). Their task was to assess and validate the initial draft of the learning product in terms of content, pedagogical suitability, and media quality. Small-Scale Trial Subjects: This group involved 2 Physical Education and Health teachers from elementary schools. This trial aimed to obtain initial feedback on the practicality and applicability of the learning model in a limited scope. Large-Scale Trial Subjects: After revisions from the small-scale trial, the study continued with the involvement of 5 Physical Education and Health teachers from several different elementary schools. This trial aimed to measure the level of feasibility and practicality of the product in a broader and more diverse context. Effectiveness Test Subjects: This group consisted of 23 elementary school students. They were the main subjects in the experiment to measure the effectiveness of the learning model on increasing interest and learning outcomes.

Research Instruments

Data were collected using multiple instruments covering cognitive, affective, and psychomotor domains:

1. Learning Interest Questionnaire (Affective Domain) Number of items: 20 items Scale: 5-point Likert scale (1 = strongly disagree to 5 = strongly agree) Indicators: attention, enjoyment, participation, and motivation
2.
3. Learning Outcomes Assessment Rubric Domains: cognitive, affective, psychomotor Psychomotor skills assessed: underhand passing overhand passing serving Scoring system: rating scale (1–5) for each performance indicator Expert Validation Sheet Used to assess content feasibility and media quality Scale: 5-point rating scale.

Study organization

The research procedure was organized following a systematic ADDIE design flow to ensure the product developed was valid, practical, and effective (Crompton et al., 2024).

Experiments to test the effectiveness of the learning model were conducted using the following steps:

a. Analysis Stage: The analysis stage aims to obtain information on the needs used to develop TGfU-based volleyball learning to improve the interest and learning outcomes of elementary school students. This stage is intended to identify preliminary sources in the form of the main issues faced and a needs analysis.
b. Design Stage: The design stage includes designing the material to be presented and gathering the materials needed to develop the model.
c. Development Stage: In the development stage, the framework generated during the design and procedural stages is realized into a product ready for implementation. The product, in the form of TGfU-based volleyball learning to improve the interest and learning outcomes of elementary school students, is assessed for feasibility by experts to obtain grades and input. d. Implementation Stage: The product produced in the development stage will be implemented with users in real-world situations. During data collection, researchers note any shortcomings and obstacles encountered during the product's implementation.
d. Evaluation Stage: Evaluation is conducted to ensure the product being developed remains up-to-date with any changes. This evaluation is conducted continuously so that even the smallest errors can be corrected immediately without waiting for the final product to be produced. Evaluation is conducted on an ongoing basis. Although the product being developed has gone through several stages by experts and can be considered complete, it must still be assessed by field practitioners, allowing for the detection of minor errors not detected in previous stages. Revisions are made based on the evaluation results or any unmet needs. If no further revisions are required, the product is considered suitable for use.
e. Product Effectiveness: After the product is developed, its effectiveness is tested. The design used in this study is a "One Group Pretest-Posttest Design." In this design, the researcher administered a pretest to the research subjects before the study began to obtain the students' initial scores. A posttest was also administered at the end of the study, which will be analyzed to draw conclusions (Suhirman & Yusuf, 2019, p. 65). The subjects of the effectiveness test were 19 students from Dingkian State Elementary School. The effectiveness test was conducted on only three volleyball techniques: underhand passing, overhand passing, and serving. Prior to this test, a pretest was conducted on the elementary school students' interest in underhand passing, overhand passing, and serving..

Statistical analysis

Data analysis was conducted using a quantitative approach to process the data collected from the questionnaire and assessment rubric. The entire data analysis process was assisted by statistical software, such as SPSS (Statistical Package for the Social Sciences) or similar software (Sugiyono, 2018). The data analysis steps are as follows:

1. Instrument Validity Analysis: Content validity is the validity estimated through testing the test content with rational analysis or through professional judgment (Widyastuti & Susiana, 2019). Data from expert validator assessments from the assessment instrument validation sheet are analyzed to determine the content validity of the product being developed. In this study, content validity was analyzed using Aiken and Gregory Validity Reliability Analysis according to (Widyastuti & Susiana, 2019) states that reliability is the extent to which the results of a measurement can be trusted only if the measurement is carried out several times on the same group of subjects. (Sugiyono, 2018) states that, "A reliable instrument is an instrument that, when used several times to measure the same object, will produce the same data." Reliability testing is carried out using inter-rater reliability (Intraclass Correlation Coefficients), Cronbach's Alpha, and Cohen Kappa. This reliability test is to see the level of agreement between experts or raters in assessing each indicator on the instrument. (Intraclass Correlation Coefficients (ICC) will provide an overview in the form of a score regarding the extent of the level of agreement given by experts or raters (Junaidi, S., & Muharram, 2021).
2. Descriptive Analysis: Descriptive statistics provide an overview or description of data seen from the average value (mean), standard deviation, variance, maximum, minimum, sum, range, kurtosis and skewness (distribution skewness) (Sugiyono, 2018). To see the level of feasibility of the game-based learning model in lower elementary schools to improve gross motor skills from the data from expert evaluations, a rating scale measurement scale was used. (Sugiyono, 2018) states that with a rating scale, the raw data obtained in the form of numbers is then interpreted in a qualitative sense. Furthermore, the results of the calculations above are interpreted using an interpretation scale. The following is an interpretation scale using a rating scale.
3. Inferential Analysis: Inferential Statistics discusses how to analyze data and draw conclusions. Inferential statistics are related to decision making (parameter estimation and hypothesis testing). Inferential statistical methods are methods related to the analysis of part of the data to forecast or draw conclusions about the entire data. After the data is collected, various statistical methods are used to analyze the data, and then interpretations are made and conclusions are drawn. Inferential statistics will produce generalizations (if the sample is representative). The normality test in this study uses the Kolmogorov-Smirnov technique with the help of SPSS version 23 for Windows. The test criteria are: (1) If the p-value > 0.05, then the data is normal. (2) If the p-value < 0.05, then the data is not normal. The homogeneity test in this study uses the Levene Test with the help of SPSS version 23 for Windows. The test criteria are: (1) If the p-value > 0.05, then the data is normal. (2) If the p-value < 0.05, then the data is not normal. Effectiveness testing using a paired-samples t-test. The paired-samples t-test is a testing method used to assess the effectiveness of a treatment, characterized by a difference in the average before and after treatment (Zou et al., 2024).

Ethical Considerations

This study adhered to ethical research standards. Informed consent was obtained from all participants and their guardians prior to data collection. Participants were informed about the purpose of the study, procedures, and their right to withdraw at any time. Additionally, this study received approval from the relevant institutional authority (e.g., school and university), ensuring that all procedures complied with ethical guidelines for research involving human participants.

Results

The development of TGfU-based volleyball learning to improve the interest and learning outcomes of elementary school students in its development uses the ADDIE method, which includes five steps: Analysis, Design, Development, Implementation, and Evaluation. The results of the assessment of a small-scale trial of TGfU-based volleyball learning to improve the interest and learning outcomes of elementary school students are presented as follows.

1. Feasibility of the Developed Model
   The feasibility of the TGfU-based volleyball learning model was evaluated through expert validation, small-scale trials, and large-scale trials. The results showed that the model was categorized as feasible, with an average score of 93.33% in the small-scale trial and 94.50% in the large-scale trial. These findings indicate that the developed learning model meets the criteria for implementation in elementary school physical education.
2. Effectiveness of the Learning Model
   To evaluate the effectiveness of the developed model, a paired-samples t-test was conducted to compare pretest and posttest scores of students' learning interest and volleyball skills.

Small Scale Test.

Table 1. Assessment Result Data from Small-Scale Trials

No	Aspect	Real Score	Max Score	%	Category
1	Appearance	43	45	92,80	Worthy
2	Material Presentation	87	91	91,72	Worthy
3	Benefits	33	38	95,49	Worthy
	Average Score	**163**	**174**	**93,33**	Worthy

Based on the Table 1, the results of the small-scale trial assessment of TGfU-based volleyball learning to increase the interest and learning outcomes of elementary school students are shown in the following Figure 3:

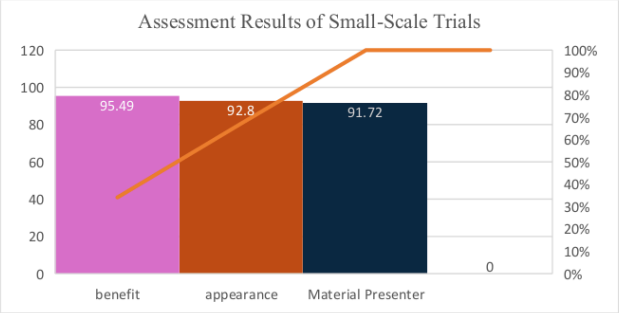

Figure 3. Assessment Results of Small-Scale Trials

Based on the Table 1 and Figure above, it shows the results of the small-scale trial assessment on TGfU-based volleyball learning to improve the interest and learning outcomes of Elementary School students, namely in the appearance aspect of 92.80% in the feasible category, the material presentation aspect of 91.72% in the feasible category, and the benefit aspect of 95.49% in the feasible category. Based on the average value of the PJOK teacher's assessment of the small-scale trial on the developed product of 93.33% in the feasible category, then the expert suggestions and input on the validation results were revised according to the validation results. The product was declared feasible for large-scale trials.

Large Scale Test

Large-scale trials were conducted at Mojoroto 1 Public Elementary School, Mojoroto 2 Public Elementary School, Ngampel 1 Public Elementary School, Ngampel 2 Public Elementary School, and Ngampel 3 Public Elementary School with 5 teachers.

Table 2. Assessment Result Data from Large-Scale Trials

No	Aspect	Real Score	Max Score	%	Category
1	Appearance	105	115	91,30%	Worthy
2	Material Presentation	219	230	95,21%	Worthy
3	Benefits	97	100	97%	Worthy
	Average Score	**421**	**445**	**94,50%**	Worthy

Based on the Table 2, the results of the large-scale trial assessment of TGfU-based volleyball learning to increase the interest and learning outcomes of elementary school students are shown in the following Figure 4:

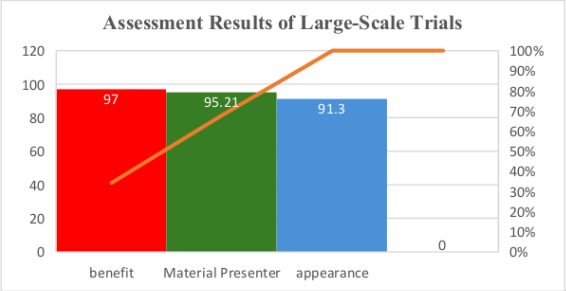

Figure 4. Assessment Results of Large-Scale Trials

Based on the Table 2 and Figure above, it shows the results of the large-scale trial assessment on TGfU-based volleyball learning to improve the motivation and learning outcomes of Elementary School students, namely in the appearance aspect of 91.30% in the feasible category, the material presentation aspect of 95.21% in the feasible category, and the benefit aspect of 97% in the feasible category. Based on the average value of the PJOK teacher's assessment of the large-scale trial on the developed product of 94.50% in the feasible category, then the expert suggestions and input on the validation results were revised according to the validation results. The product was declared feasible to be tested for effectiveness.

Discussion

1. **Interpretation of Findings**

The results of this study indicate that the TGfU-based volleyball learning model significantly improved students' learning interest and learning outcomes. This is evidenced by the increase in mean scores from pretest to posttest, supported by statistically significant results ($p < 0.05$). The improvement suggests that the implemented learning model successfully enhanced not only students' technical skills but also their engagement during the learning process. The observed improvement can be attributed to the shift from conventional technique-based instruction to a game-based learning approach. By engaging students in modified game situations, the TGfU model allows learners to actively participate, make decisions, and apply skills in meaningful contexts. This active involvement likely contributed to increased motivation and better retention of learning outcomes.

2. **Comparison with Previous Research**

The findings of this study are consistent with previous research indicating that TGfU enhances students' engagement, tactical understanding, and skill performance (Kadhum et al., 2020; Sgrô et al., 2020). Similar improvements in motivation and participation have also been reported in studies applying TGfU in volleyball and other sports contexts (Muharram et al., 2023). However, this study extends prior research by providing quantitative evidence based on inferential statistical analysis, including paired t-test results, which demonstrate a measurable improvement in both learning interest and outcomes. In addition, unlike many previous studies that focus primarily on psychomotor skills, this research integrates cognitive, affective, and psychomotor domains, offering a more comprehensive evaluation of learning effectiveness.

3. **Theoretical Explanation (TGfU Mechanism)**

From a theoretical perspective, the effectiveness of the TGfU model can be explained through its emphasis on constructivist learning principles. TGfU encourages students to construct their understanding through active engagement in game situations, rather than passively receiving instruction. The model operates through several key mechanisms:

a. Game representation: simplifying real-game situations to match students' abilities
b. Tactical awareness: helping students understand game strategies and decision-making
c. Skill execution in context: integrating technical skills within meaningful gameplay
d. Decision-making: encouraging students to think critically and choose appropriate actions

These mechanisms enable students to connect what to do with how to do it, leading to deeper learning. As a result, students are not only able to perform volleyball techniques

but also understand their application in real-game contexts, which contributes to improved learning outcomes.

4. Limitations of the Study

Despite its contributions, this study has several limitations that should be acknowledged. First, the use of a one-group pretest–posttest design without a control group limits the ability to draw strong causal conclusions, as external factors may have influenced the observed improvements. Second, the sample size was relatively small (n = 23) and limited to a specific elementary school context, which may affect the generalizability of the findings. Third, the duration of the intervention was relatively short, which may not fully capture the long-term impact of the TGfU-based learning model on students' development. Future research is recommended to use experimental designs with control groups, larger sample sizes, and longer intervention periods to strengthen the validity and generalizability of the findings.The TGfU learning model helps students achieve learning objectives by studying in groups and working collaboratively (Muharram, N. A., & Kholis, 2018). This is in line with the opinion that the TGfU-based learning concept also places greater emphasis on student activeness. Students not only develop most of their psychomotor skills, but also their affective and cognitive domains develop well (Budiarti, W. W., Hanif, A. S., & Samsudin, 2019). Furthermore, relevant research from (López-Ferrer, A., Marco-Ahulló, A., et., 2022) shows that the TGfU learning model using dodgeball as a medium can improve and develop throwing and catching skills

The TGfU model proposes the use of games, as it facilitates overcoming limitations by placing skill learning in a specific context, thus enabling game understanding and the development of tactical knowledge and enhancing problem-solving abilities through skill execution and decision-making (Muharram, N. A., & Putra, 2019). Furthermore, the TGfU model focuses on learners' learning in games education in terms of understanding game appreciation, tactical awareness, decision-making, and skill execution (Sgrô, F., Barca, M., et., 2020). Unlike the engineering approach, TGfU begins with modified games to ensure that all children can play and gain valuable insights.

Learning is also guided by asking students several questions that focus on how children focus on various tactical aspects of the game. Game-related activities are then followed by opportunities to try out potential solutions (Jariono, G., Fachrezzy, F., & Nugroho, 2020). Learning conducted through TGfU can motivate students to find new solutions to motor tasks, which may be more suitable for facilitating motor creativity (Muharram et al., 2023). The TGfU model is implemented with a holistic approach to students to provide a learning experience that leads to increased student participation and motivation in learning (Arfa, M., Akhmad, I., & Nugraha, 2019). Another advantage of TGfU is that it allows students to enjoy learning and acquire knowledge in a fun, inspiring, and creative way, transforming an activity or task into a game (Ajayati, 2017).

TGfU supports the development of game engineering skills by providing positive affective impacts and encouraging personal and social development (Sujarwo, S., Suharjana, S., et., 2021) Affective development is important because students can learn to take responsibility for their actions and develop through movement and play experiences. Through routine activities that emphasize movement and play, students' physical skills should develop well (De Waelle, S., Warlop, G., Lenoir, M., Bennett, S. J., & Deconinck, 2021). The more frequently students perform basic game movements, the more mature their movements will be, which will impact their playing skills (Madrigal, 2020). Several studies have compared the results obtained by implementing the TGfU model with other forms of learning, such as technical models (Suhairi, M., Asmawi, M., et., 2020).

Other studies highlight TGfU as an appropriate pedagogical model in physical education by promoting learning through knowledge and understanding of games/sports, thereby achieving internal or intrinsic motivation in students. Furthermore, this motivation helps them develop appropriate physical activity habits and even enjoy sports (Coutinho, P., Ribeiro, J., et., 2021). It is postulated as a pedagogically engaging model because it provides greater opportunities for student participation and increases motivation to learn (Bakhtiar et al., 2019). Based on the conclusions of this study, it is suggested that the TGfU approach can be used as an alternative in physical education teaching. Specifically, this research advises physical education teachers to be creative in achieving learning objectives by utilizing various learning models.

Conclusions

This study successfully developed and evaluated a Teaching Games for Understanding (TGfU)-based volleyball learning model using the ADDIE framework for elementary school students. The findings demonstrate that the model is feasible and statistically effective in improving students' learning interest and volleyball learning outcomes, as indicated by significant differences between pretest and posttest scores ($p < 0.05$). Rather than making overly broad claims, the results suggest that the effectiveness of the model is closely related to its ability to engage students through game-based learning, promote active participation, and facilitate contextual understanding of skills. While this study provides valuable insights, it is important to acknowledge several limitations. Firstly, the use of a one-group pretest-posttest design, without a control group, limits the ability to establish definitive causal inferences. Potential external variables not accounted for might have influenced the observed improvements. Secondly, the sample size for the effectiveness test (23 elementary school students) was relatively small and drawn from a specific context, which may affect the generalizability of the findings. Lastly, the study's duration was limited, preventing an assessment of the long-term retention of learning interest and skills. This study provides a structured and applicable learning model that can be directly utilized by physical education teachers to enhance volleyball instruction in elementary schools. Specifically, teachers are encouraged to integrate the TGfU approach to foster a deeper understanding of game tactics alongside skill development, moving beyond traditional technique-focused drills.

The model's emphasis on active participation and problem-solving within game situations can significantly boost student engagement and intrinsic motivation. Furthermore, the validated instruments (questionnaires and rubrics) can serve as practical tools for teachers to assess student progress in both affective and psychomotor domains. Future studies are recommended to address the identified limitations and expand upon the current findings. Firstly, employing more rigorous experimental designs, such as randomized controlled trials with a control group, would strengthen causal claims regarding the model's effectiveness. Secondly, involving larger and more diverse samples across different geographical locations and socioeconomic backgrounds would enhance the generalizability of the results. Thirdly, longitudinal studies are needed to examine the long-term impact of the TGfU-based learning model on students' sustained interest in physical activity and skill retention. Additionally, further research could explore the application and adaptation of this TGfU model to other sports (e.g., basketball, soccer) or different educational contexts (e.g., middle school, special education) to broaden its applicability and theoretical contributions. Finally, qualitative approaches, such as in-depth interviews with students and teachers, could provide richer insights into their experiences and perceptions of the TGfU-based learning process.

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Conflict of interest

The author declares that in the conduct of the research, preparation, and publication of this article, there were no conflicts of interest, either financial or non-financial. This research was conducted independently without any pressure, influence, or interests from any party that could affect the objectivity of the research results. The entire process of data development, testing, and analysis was conducted transparently and in accordance with applicable scientific principles.

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