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Quality of Physics Teaching Module Based on Problem-Based Learning Model Integrated with PhET Simulation on Energy and Its Transformation

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Abstract: The present work seeks to develop physics learning tools by integrating PhET simulations with problem-based learning models on energy and its transformation on Vocational High School in class X of SMK Negeri 1 Sentani. It applied the 4D model, consisting of the define, design, develop, and disseminate stages. The developed teaching modules have met the quality criteria of the learning material analyzed based on aspects of validity, practicality, and effectiveness. Based on validity, approximately 85% of the designed learning tools are categorized as Very Valid. Based on practicality, the learning implementation can be effectively applied 87.48%, and students responded very positively with a weight of 4. Meanwhile, students were actively involved based on effectiveness, with approximately 84.24% active participation. Furthermore, based on student learning outcomes, it indicated that 97% of students completed, with only 2 out of 32 students failing. Student learning outcomes tend to be higher in the cognitive domains of C4 (analysis) and C5 (evaluation) compared to C3 (application) and C6 (creation). This research resulted in the suitable learning tools for class X students at SMK Negeri 1 Sentani.

Keywords: Energy; PhET; Problem-based learning; Teaching module

Introduction

According to the Independent Curriculum, the natural science and social sciences foundations in vocational high schools are integrated into Natural and Social Sciences subjects. The structure of the vocational high school curriculum is outlined in the Attachment to the Decree of the Head of the Education Standards, Curriculum, and Assessment Agency, Ministry of Education and Culture Number 008/H/KR/2022 concerning learning outcomes in Early Childhood, Primary Education and Secondary Education in the Independent Curriculum. The Project Natural and Social Sciences subject aims to develop scientific, process, and critical thinking skills to address real-life problems. Hence, in Natural and Social Sciences learning, analyzing and optimizing critical thinking is essential for students to achieve their learning objectives (Dickson & Ampofo, 2020; Rahmawati & Katoningsih, 2023; Mutakinati et al., 2018; Cáceres et al., 2020; Miaz et al., 2023).

There is still a problem with the learning process of Natural and Social Sciences subjects in vocational high schools, particularly the challenge of contextualizing learning tools in actual terms, such as energy materials and their transformation. The fact that schools lack adequate laboratory facilities is one of the problems contributing to students' low cognitive and psychomotor ability (Latifah et al., 2024; Owan et al.,

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2022). For instance, the average score for Physics in the class XII school exams of the 2020/2021 academic year is 65, while the average score for Natural and Social Sciences in the class X final semester exams of the same year is 70. These scores did not meet the minimum passing criteria of 75, which is set in the leger archives of Vocational High School in SMK Negeri 1 Sentani, Papua for the 2020–2021 academic year. This demonstrated that the students' competencies had not met the target set in the learning objectives.

This problem is aggravated by teachers' conventional teaching methods, such as lectures, and other forms of non-digitally created material. Additionally, during the Covid-19 pandemic, the use of online-based learning or a remote learning system further decreased students' interest in learning due to the lack of innovative teaching approaches. Teachers have mainly relied on video-equipped teaching media such as PowerPoint, but they have not simulated laboratory-based work to enhance students' learning creativity in integrated physics subjects with social phenomena. However, physics learning requires analysis and concept verification through laboratory activities, which aid students in developing process skills, motor skills, and a scientific attitude in testing the validity of physics theories with empirical data (both quantitative and qualitative). Due to this, schools are required to offer both physical and virtual laboratories that promote student-centered physics study (Rutta et al., 2021; Meyer, 2023; Maghfirah et al., 2022; Pyatt & Sims, 2012; Husnaini & Chen, 2019).

However, the fact that occurs in the mentioned school is the lack of laboratories. This hinders student-centered learning, which limits students' ability to analyze problems and solutions related to physics concepts, such as energy and its transformation. As a result, students become disengaged and bored, leading to a decline in the quality of the learning process and student outcomes (Bergdahl et al., 2020).

On the other hand, Vocational High School in SMK Negeri 1 Sentani, has a sufficient computer lab to support teachers in creating materials utilizing virtual laboratories. This implies the need for innovative teaching methods to create a student-centered learning environment using virtual or computer-based laboratories. Physics Education Technology (PhEt) is a virtual laboratory simulation application containing physics concepts (Wu & Huang, 2007; Maulidah & Prima, 2018; Putra et al., 2021).

PhET is an interactive simulation that helps students link real-life phenomena with the underlying principles of physics, expanding their comprehension and fostering their interest in physics. Studies by Pratiwi et al. (2022) and Safitri et al. (2022) have shown that PhET simulations, with their engaging audio-visual design, enhance students' understanding and improve their learning outcomes in science. PhET simulations are proven to improve student activity and learning outcomes (Segening et al., 2022). PhET is particularly significant in problem-solving since it can increase students' access to produce and represent concepts. Integrating PhET with the Problem-Based Learning (PBL) model is a practical approach. PBL is a teaching model that uses real-life problems to help students develop critical and creative thinking skills. Teachers present engaging problems related to the real world, and students analyze and formulate alternative solutions to these problems (Rahayu et al., 2017; Yusuf & Rahman, 2019). PBL is an effective teaching model for Natural and Social Sciences in education. It involves using real-world problems as a context for students to develop problem-solving skills (Oktavia et al., 2018). In the PBL model, students actively search for solutions to problems. This approach improves their critical thinking, understanding, and learning outcomes. It also encourages participation, promotes democracy in learning effectiveness, and fosters creativity.

This is in line with the explanation by Gunawan et al. (2021) that students are encouraged to think creatively by solving everyday problems related to nature using physics concepts. Therefore, in a PBL scenario, students are guided to conduct real research to address the problems presented by the teacher. Researchers are interested in creating this learning design as PBL has been underutilized in SMK Negeri 1 Sentani. Currently, teachers primarily rely on lecture-based teaching using non-interactive PowerPoint media. Therefore, the researchers plan to develop a learning tool integrating the PBL instructional model with a virtual laboratory using PhET simulations. This resource refers to the independent curriculum and is presented as teaching modules.

Teaching is a comprehensive educational tool that includes the syllabus, activity stages, assessment, and reflection. According to Kepmendikbudristek No. 56/M//2022, a teaching module is a document that outlines the objectives, steps, instructional media, and assessment required for a specific unit or topic based on the learning objectives. In addition, according to Maulida (2022), a teaching module is a learning tool or learning design based on the curriculum to achieve the set competency standards. Thus, the current learning design known as a teaching module is a new term for Lesson Plans, but there are differences between the two. Teaching modules are developed by schools based on the Education Unit Operational Curriculum prior to the start of teaching. They consist of three essential components: learning objectives, learning steps following the learning model, and assessment (Syakur et al., 2023; Hauer & Quill, 2011; Fatimah et al., 2024).

Hence, the teaching module developed in this research will be analyzed for its quality to ensure its suitability in terms of validity, practicality, and effectiveness. Based on the mentioned problems, this study aims to analyze the quality of a teaching module developed for PBL, integrated with PhET simulations, on energy and its transformation in SMK Negeri 1 Sentani.

Method

This development study follows the 4D model, in line with Thiagarajan et al. (1974). The 4D model consists of four stages: define, design, develop, and disseminate, as depicted in Figure 1.

The define stage is the initial phase that seeks to identify the problems and specify the learning requirements. It involves analyzing various aspects such as: Front-end analysis which aims to identify the student's characteristics, individual student academic ability, learning styles, as well as infrastructure that fosters learning energy theory and its transformations in physics; analysis of students' learning conditions; analysis of physics concepts, and; analysis of learning objectives.

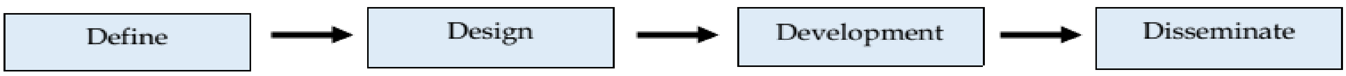


Figure 1. Research design of 4D model development

The design stage is the second stage focuses on designing the teaching module based on the analysis conducted in the define stage. The module follows the format of the independent curriculum and with learning steps that integrate the PBL model with PhET simulations. Next, the third stage is development stage. This stage involves producing a high-quality teaching module through two steps: expert appraisal followed by revision, and developmental testing. The objective is to create the final form of quality teaching modules. And the last stage is the dissemination stage. The dissemination stage is the final phase of the development process aimed at promoting the developed product to ensure its acceptance by users, whether individuals, groups, or systems. This involves selective packaging and collaboration between producers and distributors.

Therefore, assessing the quality of the developed teaching module is necessary. According to Nuryadi et al. (2017) the quality of a product, design, development, and program evaluation must meet the criteria of validity, practicality, and effectiveness. A product or program is considered valid when it reflects the essence of knowledge (state of the art of knowledge), which is known as content validity. Practicality means that users find the product usable, meanwhile, effectiveness refers to the product's ability to achieve the intended goals set by the developers.

Validity refers to the degree of accuracy of an instrument (measurement tool) that it intends to measure. In the learning process context, a research and development products are assessed through content validity and construct validity. According to Prilianti et al. (2018), the validity of teaching tools is assessed by expert validators who focus on its appearance, language, and content. Practicality is assessed based on user feedback and the usability of the developed product (Susilawati et al., 2022). In evaluating the practicality of teaching tools, two aspects are considered the implementation of the learning process and student responses. A teaching device is considered practical if it meets the criteria of practicality, which can be analyzed through teacher observations or student response.

Effectiveness. This word derives from the term effective based on KKBI (*Kamus Besar Bahasa Indonesia*), which indicates to have an effect, influence, or result. According to Alfiriani et al. (2017), effectiveness is the aspect of achieving learning objectives utilizing developed learning tools products. This aligns with the research by Mustami (2017) that the effectiveness of learning tools is measured by assessing students' learning outcomes. Further, active student activity in organizing and discovering information indicates teaching effectiveness (Handayanti et al., 2020). This research assesses effectiveness based on students' learning activities and learning outcomes that align with the formulated learning objectives.

In this study, three experts were used in this study's validity assessment for the format, language, and content items. Meanwhile, the practicality is examined during limited trial sessions in three meetings, focusing on the implementation of the learning materials and student responses. Further, the effectiveness is analyzed based on student activities and learning outcomes. Therefore, a limited trial design using an experimental research design, specifically a quasi-experimental design with a one-group pretest-posttest design in Figure 2. The design involved a single class without a control group. Students took a pre-test before and post-test after the learning process.

Q_1	**X**	**Q_2**

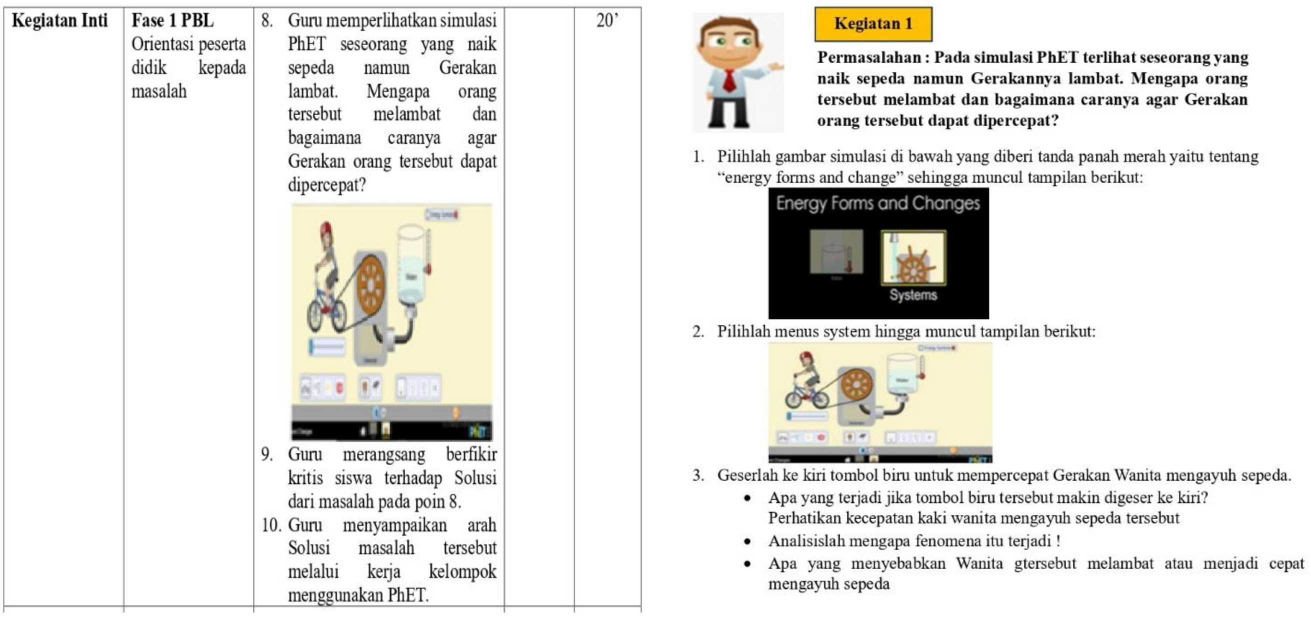
Figure 2. Design of one-group pre-test post-test

Result and Discussion

Based on the analysis conducted in the define stage and considering students' learning styles, the developed instructional materials in this study use a PBL model integrated with the PhET simulation application. The curriculum-based module consists of aspects, including: general information, core components, learning scenarios or stages, teacher reflection, student reflection, assessment, student worksheets, and learning materials.

The developed instructional module stands out for its adherence to the Merdeka curriculum format and its integration of PBL model and PhET simulation in the learning process. This module stimulates students' critical thinking by connecting energy to human life and the universe. For instance, the learning objective in the first meeting is for students to accurately connect the concept of energy to human life and the universe. The learning steps design integrating PBL and PhET simulation is depicted in Phase 1 of PBL, in which the "teacher presents the problem" using the PhET simulation (Figure 3). The problem presented through the PhET simulation involves a person riding a bike, but their movement is slow, causing the bike wheel to weaken and not generate other forms of energy. Why is the person slowing down, and how can their movement be accelerated? Students used the student worksheet to discover the answer, and as a result, the student worksheet was created, as seen in Figure 3.

The student worksheet guides students with step-by-step instructions and questions related to the presented problem in Phase 1 of PBL, helping them find the solution.



Kegiatan Inti	**Fase 1 PBL** Orientasi peserta didik kepada masalah	8. Guru memperlihatkan simulasi PhET seseorang yang naik sepeda namun Gerakan lambat. Mengapa orang tersebut melambat dan bagaimana caranya agar Gerakan orang tersebut dapat dipercepat? 9. Guru merangsang berfikir kritis siswa terhadap Solusi dari masalah pada poin 8. 10. Guru menyampaikan arah Solusi masalah tersebut melalui kerja kelompok menggunakan PhET.		20'

(a)

Kegiatan 1

Permasalahan : Pada simulasi PhET terlihat seseorang yang naik sepeda namun Gerakannya lambat. Mengapa orang tersebut melambat dan bagaimana caranya agar Gerakan orang tersebut dapat dipercepat?

1. Pilihlah gambar simulasi di bawah yang diberi tanda panah merah yaitu tentang "energy forms and change" sehingga muncul tampilan berikut:
2. Pilihlah menus system hingga muncul tampilan berikut:
3. Geserlah ke kiri tombol biru untuk mempercepat Gerakan Wanita mengayuh sepeda.
   - Apa yang terjadi jika tombol biru tersebut makin digeser ke kiri? Perhatikan kecepatan kaki wanita mengayuh sepeda tersebut
   - Analisislah mengapa fenomena itu terjadi !
   - Apa yang menyebabkan Wanita gtersebut melambat atau menjadi cepat mengayuh sepeda

(b)

Figure 3. (a) Integration between the PBL learning model and PhET simulation, (b) PBL-based worksheet design and PhET simulation

The teaching module design in this study is comprehensive and up-to-date compared to previous development of learning tools by Safitri et al. (2022), which only focused on student worksheets, and Pratiwi et al. (2022), who did not use an independent curriculum format and did not include cognitive diagnostic stages. Additionally, the integration between PBL and PhET simulations has started from phase 1 of PBL, which involved orienting students to the problem, and it becomes the basis for students to identify solutions through student worksheets in phase 3 of PBL using PhET simulations.

Furthermore, the assessment instrument for learning outcomes includes PhET-based essay tests. These tests aim to evaluate students' learning outcomes in the cognitive domains of C3 (application), C4 (analysis), C5 (evaluation), and C6 (creation). However, the developed teaching module must be assessed for its validity, practicality, and effectiveness during the development phase.

Quality of Teaching Modules Based on Validity Aspects

The teaching module in this study follows the format of the independent curriculum, which also serves as the foundation for the assessment format. The expert validator in Physics Education provided feedback and suggestions for improving the teaching module. The feedback mainly focused on adapting the format to the independent curriculum, enhancing the design of student worksheets and teaching materials, and including the developer or teacher name in the module format. The validator made recommendations regarding the language aspect, including: simplifying sentence structures for better understanding by students, clarifying instructions in the student worksheets format of the use of PhET simulations relevant to the material, and correcting repeated sentences in both the student worksheets and teaching materials. While there are validator recommendations for the content, including: Align the learning steps with the PBL model and indicate the integration pattern between PBL and PhET simulations, improve the instructions in the PhET-based student worksheets by adding relevant physical variables or parameters to help students grasp the intended learning concepts, align the assessment aspects with the learning objectives and is HOTS-based, and develop a matrix or grid for the learning outcome test.

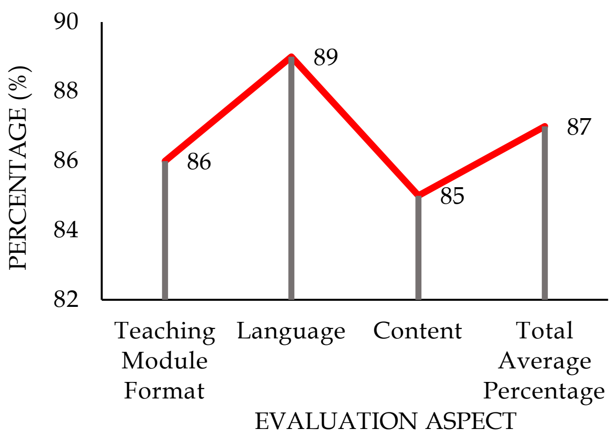


Figure 4. Results of the teaching module validity evaluation

Researchers used the validator's recommendations as the foundation for revising the teaching modules, including creating a test assessment grid. The validator then reassessed the module. The final validation results which are depicted in Figure 4, indicate that the module is very suitable, with an assessment score of approximately 87%. The content aspect has a lower percentage (85%) compared to the format and language aspects, although it is still in the very valid category. While the language aspects possess a high percentage (89%). Thus, the teaching module developed by the researcher is very valid and suitable for use without any further revisions.

Quality of Teaching Modules Based on Practical Aspects

The practicality of the teaching module developed is assessed based on the implementation of the teaching and learning process and the students' responses during the module's trial. According to Figure 5, the teaching and learning process implementation scored approximately 87.48%. The teacher successfully implemented all stages of the teaching module. Comparing the introductory and core activities, the closing stage had a higher implementation percentage (90.72%). Meanwhile, the teacher can successfully complete 86.99% of the core stage activities.

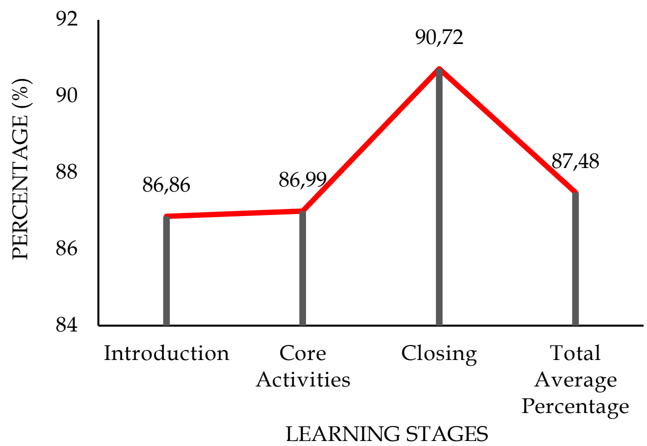


Figure 5. Percentage of learning implementation by teachers

The observation results on the implementation of the introductory stage showed that the teacher's activities tended to have a higher average percentage, particularly in the first and second meetings of the two observers, namely the teacher's activity in preparing students' mentally and physically to learn with enthusiasm (92.50%). However, the teacher's involvement in providing basic cognitive diagnostics and prompting questions received a relatively lower average percentage (83.17%).

In the core activities, the highest percentage of teacher's implementation is seen in the activity where students present their work (93.30%). The lowest percentage is observed in Phase 1 of PBL (orienting students to the problem), specifically in the activity where the teacher introduces the problem phenomenon through PhET simulation (81.50%). In addition, the teacher's reinforcement activity in Phase 5 decreased from the second meeting (86%) to the third meeting (81.50%). The teacher's management of the learning activities is expected to improve with their preparedness in the teaching process.

The closing stage's percentage reveals that the teacher's activity is particularly effective when she leads the class to end the session by praying together (92.17), while the lowest percentage is found in the teacher's reflection activity (88.50%). Overall, the implementation percentage of the teaching module developed in this study is considered excellent (87.48%). This indicates that the designed teaching module is efficient in implementing the teaching and learning process.

Meanwhile, the students' response to the learning process using the developed teaching module can be seen in Table 1. Student responses are assessed based on five sub-indicators: participation in the PBL and PhET-based learning phases, solving the formulated problems, using PhET, understanding the material, and completing the student worksheet steps.

Table 1. The score of Students' Response

Indicators	Score of sub indicators					Average
	1	2	3	4	5	
Simplicity	4	3	3	4	3	3
Interest	3	4	4	4	4	4
Punctuality						3
Total						3

Table 1 shows student responses to the developed teaching module included in the good category with a maximum score of 3. The indicator with the highest score is the interest indicator, scoring 4 compared to the indicators of simplicity and punctuality. Students were highly interested in the teaching module that utilized PhET simulations. They were interested in the problem presented by the teacher using PhET, using PhET, understanding the material, and completing PhET-based students worksheet stages.

However, in the simplicity aspects, student responses were not yet excellent but rated as good with a score of 3 for the following items: finding solutions to problems, ease of using PhET simulations, and ease of completing the student worksheets steps. Meanwhile, the items considered "very easy" for students were: following the PBL steps, ease in comprehending the materials. This indicated that with the use of the developed teaching module, students are interested in PhET simulations and easily understand the physics concepts related to energy and its transformation. However, they still require assistance in problem-solving, utilizing the PhET simulations effectively, and the teacher guidance in completing the student worksheet steps.

The student response data indicates that this teaching module is practical to use. Thus, the developed module is highly practical, as seen from its implementation and the students' response. However, the findings of this study point out that PBL in phases 1 and 2 of PBL, teachers need to be creative in linking the presented problem to real-life situations relevant to energy and its transformations. In this learning activity, students were highly interested and at ease in using the PhET simulations, although they faced some challenges in finding solutions to problems. In terms of time, students considered the learning activity to be well-implemented.

The Quality of Teaching Modules Based on Effectiveness Aspects

The aspect of the teaching module's effectiveness was evaluated based on student activity and learning outcomes. Figure 6 indicates that the average percentage of student activity at the learning stage is approximately 84.24% or the very good category.

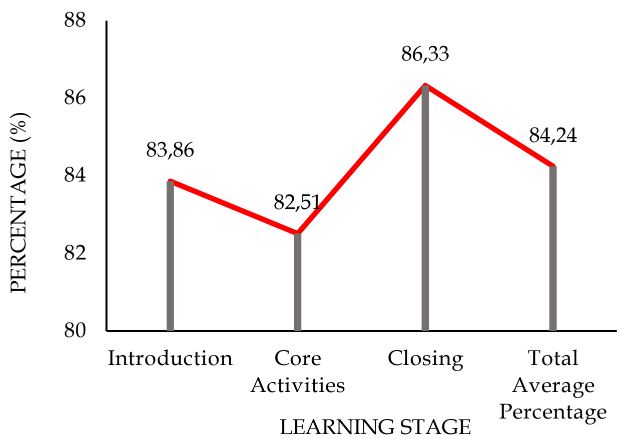


Figure 6. Percentage of student activity

However, student participation in the core activities was lower (82.51%) compared to the introductory and closing activities. Specifically, students showed less enthusiasm in receiving information about the presented problem (78.50%) and expressing opinions about the solution (77.10%) during the first phase of PBL. This is in line with the teacher's activities during the learning implementation, which requires creativity in guiding students to explore critical thinking skills, especially in finding solutions to problems related to the concepts of energy and its transformation (Apino & Retnawati, 2018; Hidayah et al., 2021). In summary, students' overall activity level in using the developed teaching module is excellent, with an average percentage of approximately 84.24%.

The effectiveness of the teaching module, particularly student learning outcomes, indicates that the developed module has achieved 97% of students (30 out of 32) completing the energy and its transformation. The developed teaching module has proven to be effective in achieving its intended goals. This was also seen in the students' learning outcomes in the analysis domain (C4), which had a higher percentage (86%) compared to C3, C5, and C6. Additionally, the cognitive domain (C5) showed a higher percentage (85%) compared to C3 (84%), although C6 is only 81%.

The analysis of students' responses to C4 questions reveals their ability to determine the required energy when a person is on a slide with a specific height, simulated through PhET in Figure 7. Students are requested to examine the child's kinetic energy at two different heights, namely when he is at heights A = 1.5 meters and B = 1 meter (C4), for a child whose mass is 30 kg and the overall height of the inclined plane is 2 meters. It was discovered that approximately 86.28% of students provided accurate answers. Students analyzed the problem by finding the sliding speed of the child at different heights, influenced by the earth's gravitational force (Rustana et al., 2020; Agu, 2023). This allowed them to determine the kinetic energy at points A and B, taking into account the child's mass and speed of the child if frictional force is neglected.

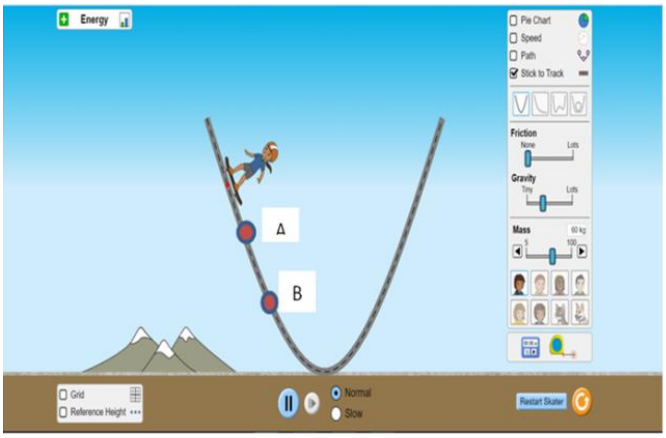


Figure 7. PhET simulation example in the test instrument to measure learning outcomes in the cognitive domain C4

Based on the analysis of validity, practicality, and effectiveness, it is found that this teaching module has good quality and is suitable for use without any revisions on Vocational High School in class X of SMK Negeri 1 Sentani. However, teachers should also possess proficiency in the PBL teaching model and PhET simulations to implement this module effectively (Putranta & Wilujeng, 2019; Banda & Nzabahimana, 2023). Furthermore, in implementing the teaching module, especially in vocational schools, it is essential to have computer facilities or digital devices for students to utilize PhET. Through this development research, it is also possible to develop teaching modules that use an independent curriculum format that employs a learning model that stimulates students' critical thinking, such as the PBL model (Wechsler et al., 2018; Song & Cai, 2024). Meanwhile, the lack of physics laboratory facilities can be addressed by developing teaching modules that utilize PhET simulations, stimulating student interaction, and enhancing higher-level cognitive competencies such as C4 and C5.

Conclusion

The developmental research using the 4D model has successfully created teaching modules for Vocational High School in SMK Negeri 1 Sentani, focusing on the topic of energy and its transformations, following the format of the independent curriculum. The teaching modules were developed by integrating PBL with PhET simulations. Based on validity, it indicated that around 85% is valid, which means it is included in the Very Valid category. The practicality aspect shows that it can be carried out very good (87.48%). Meanwhile, the effectiveness aspect in the student activity indicator revealed that the students are very active (84. 24%), while based on student learning outcomes, it is shown that 97% of students complete. This research resulted in the development of a learning tool in the form of a teaching module that is suitable for the students' characteristics and the PhET-based learning facilities at SMK Negeri 1 Sentani.

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Author Contributions

Muhammad Yusuf: Conceptualization, writing—original draft preparation; Raghel Yunginger: Methodology, validation; Riris Nainggolan: Curation, writing—review and editing, formal analysis.

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Conflicts of Interest

The authors declare no conflict of interest.

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