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Enhancing Students' Science Process Skills Through Design Worksheet-Based Inquiry Integrated PhET Simulation on Acid and Base Material

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Abstract. Integrating PhET on inquiry-based worksheets can foster a more interactive and hands-on learning environment that encourages active student participation throughout the educational process. The research aims to develop an integrated inquiry-based worksheet PhET simulation. This research type is R&D, using the 4-D model, which designs learning activities to enhance science process skills. The validators totaled four people, including media experts, content experts, and two practitioners. The readability test uses ten for 9th-grade students. The research findings indicate that the worksheets created have a very high average validity, with an Aiken V value of 0.97. The readability test results were obtained with an average readability percentage of 96% in the very good category and without revision. The effectiveness of the worksheets developed to improve science process skills obtained an N-gain of 0.71 in the high category. This means that PhET simulation integrated inquiry-based worksheets are feasible, practical, and effective for science learning to improve science process skills.

Keywords: Worksheet, Inquiry, PhET simulation, Science process kills

Introduction

In the modern age, people need to be proficient in multiple skills. One of the crucial ones is science process skills. This skill, starting from the essential ability to observe phenomena, then develops into more complex skills (Mahmudah et al., 2019), has a vital role in science learning (Sideri & Skoumios, 2021; Sibiç & Acar Şeşen, 2022; Sarıoğlu, 2023; Senisum et al., 2022), a critical skill that students should cultivate during their science education (Gizaw & Sota, 2023).

Science process skills encompass more than just formal education. They also incorporate identifying capabilities, creativity, ethical standards, and student conduct anticipated to be applied by students in their everyday lives (Maison et al., 2019). Science process skills enable students to grasp scientific concepts more rapidly and accurately (Inayah et al., 2020), bridge understanding of science concepts (Abungu et al., 2014), and develop skills for problem-solving (Gizaw & Sota, 2023; Widyaningsih et al., 2020), allow students to carry out research studies to collect extensive data (Bulent, 2015), To uncover the vital importance of inquiry-based methods in education (Ongowo & Indoshi, 2013), use reason, mind, and attitude effectively and efficiently to achieve learning outcomes (Gürses et al., 2015).

In the learning process, there need to be steps to make it easier and more efficient, which is called the learning model. One approach that aligns well with hands-on learning and developing scientific process skills is the inquiry model of instruction. The inquiry model serves as an approach to comprehending scientific ideas and observable events (Abd-El-Khalick et al., 2004). Inquiry-based learning is prevalent in science learning (Pedaste et al., 2015), learning by using the inquiry model can improve learning outcomes (Sutarningsih, 2022), the inquiry model is effective in influencing critical thinking skills (Islami & Soekamto, 2022), in enhancing science process skills (Ramayanti & Lismaya, 2019; Putri & Harahap, 2019; Nosela et al., 2021).

Practicum-based learning needs a laboratory as support, but in some schools in Indonesia, the lack of laboratory availability is one of the problems faced. To overcome this, there is a need for virtual laboratory facilities, one of which is PhET simulation, a free software developed by the University of Colorado in America (Muzana et al., 2021). Although PhET uses physics terminology, its scope is broader. This tool also covers other fields of science, such as chemistry, biology, geoscience, and mathematics (Durkaya, 2023); PhET can help students understand abstract concepts in science (Rizaldi et al., 2020). Interactive PhET simulations offer visual representations and educational tools that facilitate effortless comprehension of complex ideas (Haryadi & Pujiastuti, 2020; Ng & Chua, 2023).

Learning using PhET media with actual practicum is more effective than relying on real practicum alone. (Maulina & Kustijono, 2017). PhET simulations make students more active and enthusiastic about learning (Muzana et al., 2021). PhET also has the advantage of visualising abstract physics concepts that are not easy to observe directly (Sari et al., 2021; Saudelli et al., 2021). PhET helps to understand concepts easily to increase motivation and learning outcomes (Banda & Nzabahimana, 2023). Using PhET can improve students' academic achievement (Mallari, 2020), contributing positively to science learning (Özcan et al., 2020).

To adapt to modern times, science education must shift from a teacher-centered approach to a student-centered one. In science learning, students must be more active by being given as many opportunities as possible to carry out the learning process. One way to enable student learning activities is by providing worksheets. Worksheets serve as instructional resources that guide students through active participation in their learning process (Pawestri & Zulfiati, 2020). Worksheets contain information, instructions, and guiding questions (Farida et al., 2019). The learning activities focused on science process skills are structured and directed by worksheets (Dewi et al., 2018), Assisting students in comprehending the procedural abilities and theoretical ideas they have acquired (Dewi et al., 2022; Nurfadhillah et al., 2018). Therefore, the development of worksheets is significant to be implemented in schools. Worksheets can improve learning outcomes (Kuswari & Choiruddin, 2021), creative and critical thinking (Harwati & Rokhmat, 2021), and science process skills (Arifullah et al., 2020).

The material chosen in the development of PhET simulation-based inquiry-based student worksheets is Acid and Base because this material at the junior high school level rarely has practicum activities due to the lack of availability of equipment and through the analysis of the topic of acids and bases as taught in middle school curricula, so it is very suitable for using PhET simulation learning media. Student worksheets integrated with PhET simulation increase students' activities and activeness. Students only scan the QR Code on the worksheet and immediately start practicum activities. Integrating inquiry-based student worksheets enhances the validity, practicality, and effectiveness of PhET simulations. Previous research shows that inquiry worksheets integrated with STEM on acid-base material have exciting criteria and are suitable for use as teaching materials (Hasibuan et al., 2023), worksheets based on guided inquiry on acid-base material to improve creative thinking (Sulistiani & Agustini, 2022). Therefore, based on the explanation above, this study aims to develop an inquiry-based worksheet integrated with PhET simulation to improve students' science process skills for 9th grade in Junior High School.

Methods

This study uses the Research and Development (R&D) methodology. It follows the 4-D model, which consists of four phases: define, design, develop, and disseminate (Thiagarajan et al., 1974). The 4-D model is a development model that can be used to develop different types of learning media (Arkadiantika et al., 2020). The 4-D model is suitable for developing teaching materials based on learning objectives (Dermawan & Fahmi, 2020; Kosassy, 2019). The advantage of the 4-D model is that it does not take long because the stages are relatively not too complicated (Maydiantoro, 2019). The phases in the 4-D Model's development process are illustrated in Figure 1.

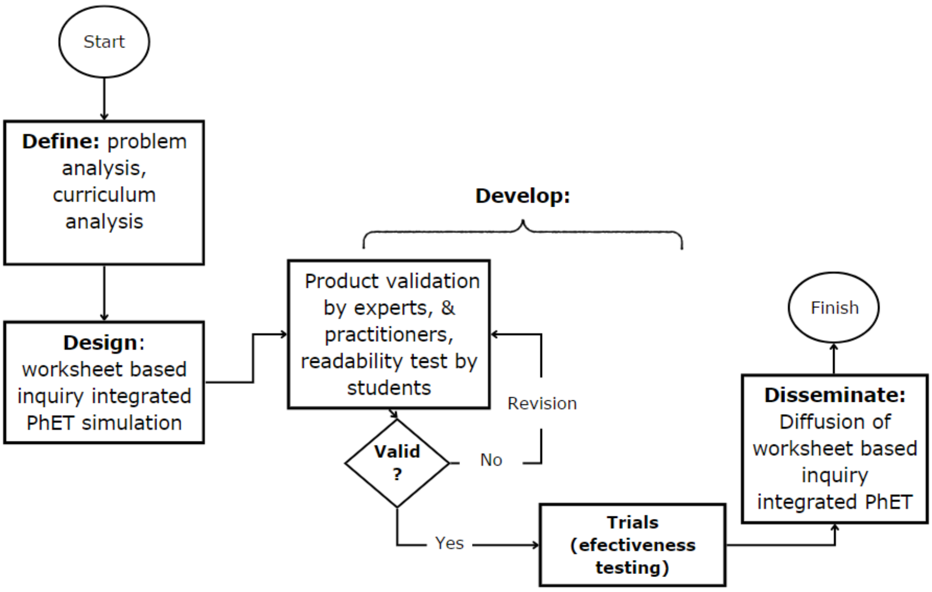

Figure 1 Research Stages with 4-D Model

This study uses four validators: a media expert, a content expert, and two practitioners. Their role was to assess the validation of the developed student worksheets. Additionally, 10 ninth-grade students participated in a readability test to evaluate the product's practicality. Field trials to assess the effectiveness of the worksheet were conducted by randomly selecting one 9th-grade class, totalling 30 students at SMPN 1 Nunukan, as the sample. The research type is pre-experimental, using a one-group pretest-posttest design, as illustrated in Table 1.

Table 1 One Group Pretest-Postest Design

Pretest	Treatment	Posttest
T_1	X_1	T_2

Information:

T1 = Test before learning
X1 = Learning with PhET integrated inquiry-based worksheets
T2 = Test after learning

The validation sheet and student responses related to the readability test used a 4-point Likert scale, as shown in Table 2.

Table 2. Likert Scale Criteria

Criteria	Score
Very good	4
Good	3
Less	2
Very less	1

Data was collected by administering 5 multiple-choice questions based on science process skills in the pretest and posttest. These questions were then analyzed using MS Excel to obtain the gain score and determine the impact of PhET-integrated, inquiry-based worksheets on improving students' science process skills. The worksheets focus on acids and base materials. Table 3 outlines the various aspects of science process skills.

Table 3. Science Process Skills Instruments

Aspects	Question Indikator
Observing	When doing a practicum by dipping litmus paper in a vinegar solution, students can mention the observed results.
Classifying	According to the results of the virtual experiment, students can name the general properties of the base.
Measuring	In a virtual simulation measuring the concentration of an OH- ion solution, students can determine what the pH of the solution is.
Predict	When experimenting with adding water to a solution, students can predict what will happen to its pH.
Conclude	After conducting a virtual experiment with various solutions and finding that one has a certain pH, students can conclude the solution's properties.

To measure the validity of the worksheet so that it is suitable for use, namely using the Aikens' V, it can be seen in equation 1:

$$V_{aiken} = \frac{\sum S}{[n(c-1)]} \qquad (1)$$

Information:

S = r – lo
V = Aiken validity index
c = highest validity rating number
n = number of validators
Lo = lowest validity rating
r = number given by the validator

Table 4. Aiken's V Validity Criteria

Aiken V index	Criteria
0.8 < V ≤ 1	Very High
0.6 < V ≤ 0.8	High
0.4 < V ≤ 0.6	Medium
0.2 < V ≤ 0.4	Low
0.0 < V ≤ 0.2	Very Low

(Rahmat et al., 2024)

The readability test questionnaire was analysed by calculating the average assessment score given to ten 9th-grade students. The average score of all aspects of the assessment was calculated using Equation 2.

$$P = \frac{n}{N} \times 100\% \qquad (2)$$

Information:

P = percentage of readability
n = score obtained
N = max score

The average score will later be converted into a qualitative value based on the score conversion guidelines in Table 5, which includes five scales.

Tabel 5 Readability Test Score Conversion

Readability Test (%)	Category	Information
>80	Very good	Unrevised
70 - 80	Good	Unrevised
60 - 69	Enough	Revised
50 - 59	Less	Revised
<50	Very less	Revised

(Pratiwi et al., 2014)

To see the product's effectiveness in improving science process skills, looking for the gain value using Formula 3 is necessary.

$$N - gain = \frac{S_{posttest} - S_{pretest}}{S_{maximum} - S_{pretest}} \quad (3)$$

The N-gain results are categorised into three groups, as shown in Table 6 (Saputri & Tirtoni, 2022).

Tabel 6 N-Gain Value Criteria

Nilai	Kriteria
N-gain > 0.7	High
0.3 < N-gain ≤ 0.7	Medium
N-gain ≤ 0.3	Low

Results and Discussion

The first stage in this research is to define. Several activities are carried out at this stage, including analysing student and teacher problems. Information was obtained through interviews that practicum activities were rarely carried out in this material because of the lack of laboratory facilities and equipment, so learning was only textual and measured cognitive achievements. Learning activities use direct learning that is still teacher-centred and has not yet utilised PhET simulation, which is integrated into student worksheets. The next activity, curriculum analysis, namely the material used, is adjusted to the features of the PhET simulation, analysing how well the content aligns with intended educational results and goals. A worksheet is adjusted to the stages of the inquiry.

The second stage is design. At this stage, the worksheet is designed in the Canva app and then converted to PDF, as you can see in the initial view of the worksheet in Figure 2.

Figure 2. Worksheet Initial View

At this stage, students learn activities on the worksheet that follow the structured steps of the inquiry, including orientation, problem formulation, data collection, data analysis, and conclusions. The student worksheets are also integrated with the PhET simulation, where students only scan the QR Code on the worksheet, which is directly connected to the PhET simulation in the acid and base experiments. Students immediately carried out practicum activities on their respective smartphones. For more details, see Figure 3.

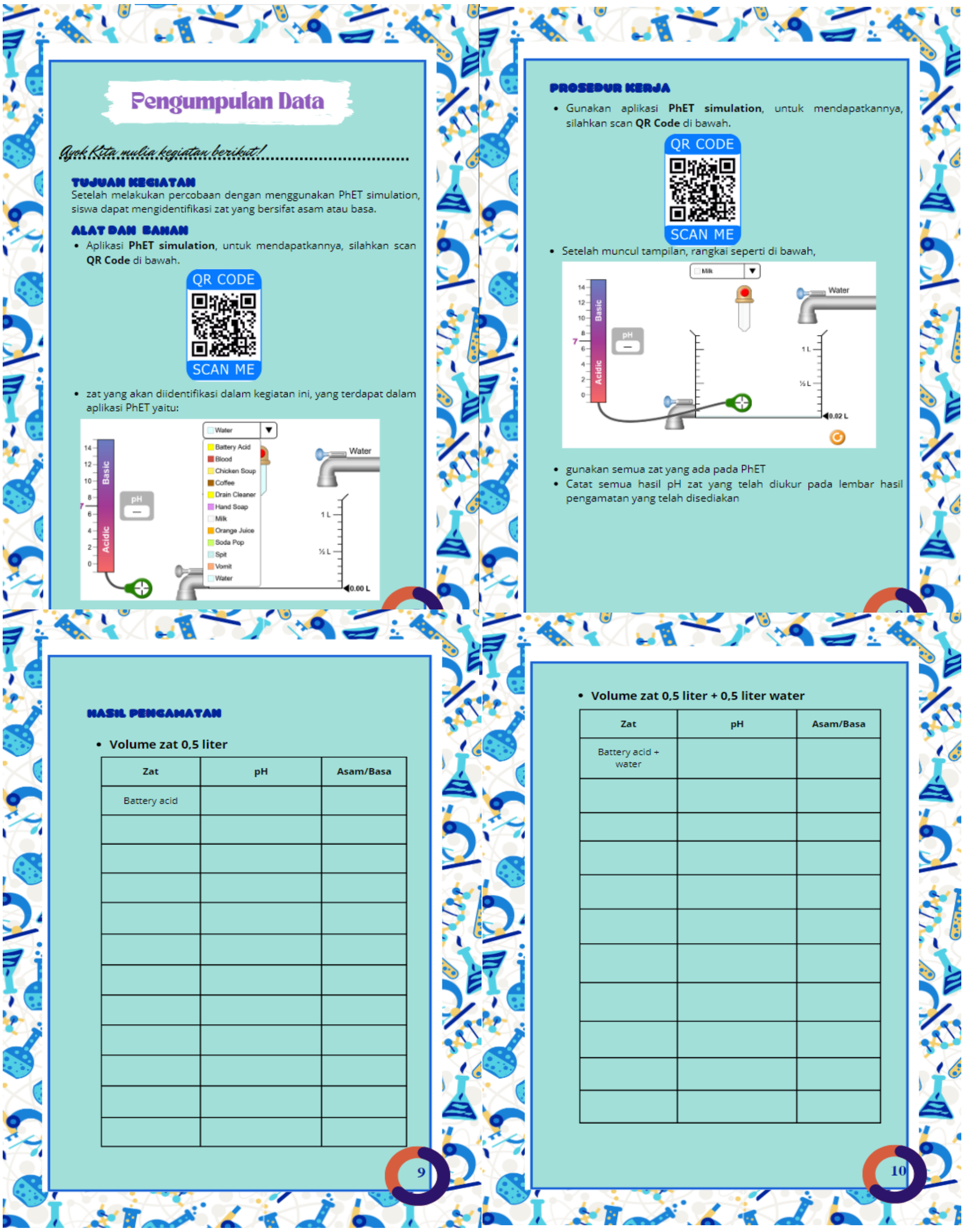

Figure 3. Learning Activities

Figure 4 shows learning activities following the inquiry model structure of data analysis and conclusions.

Figure 4. Data Analysis and Conclusion Activity

The third stage is development. During this stage, the designed worksheets need to be validated by validators. Worksheets are validated by whatever validators are available, namely media experts, content experts, and 2 practitioners. The validation results from the validators are shown in Table 7.

Table 7. Results of Validation of Developed Worksheets

Assessed Aspects	Validators				Index	Category
	Media expert	Content expert	Practitioners 1	Practitioners 2		
Eligibility Content: Suitability of material with learning outcomes and objectives	4	4	4	4	1	Very High
Accuracy of the material	4	3	4	4	0.92	Very High
Encourage students' curiosity	4	4	4	4	0.92	Very High
Eligibility of Serving: Serving technique	3	4	4	4	0.92	Very High
Serving support	4	4	4	4	1	Very High
Presentation of Learning	3	4	4	4	0.92	Very High
Conformance with inquiry models	4	4	4	4	1	Very High
Compatibility with improve science process skills	4	3	4	4	0.92	Very High
PhET simulation integration: Suitability of PhET simulations to materials	4	4	3	4	0.92	Very High
Ease of use of PhET simulations	4	4	4	4	1	Very High
Contribution of PhET simulation to concept understanding	4	4	4	4	1	Very High
Language Qualifications: Straightforward and communicative	4	4	4	4	1	Very High
Dialogical and interactive	4	4	4	4	1	Very High
Suitability with student development	4	4	4	4	1	Very High
Conformity with language rules	4	4	4	4	1	Very High
Average Aikens' V index	58	58	59	60	0.97	Very High

Table 7 is the validation result of the worksheet developed. The validators consisted of 4 people, namely media experts, material experts, and two practitioners who were science teachers. The validation results with Aikens' V averaged 0.97 for all aspects and indicators with a very high category, showing that the PhET simulation integrated inquiry-based worksheet is feasible for science learning.

After the validator validates this worksheet, ten students who have been selected test it for readability. The results of the readability test are shown in Table 8.

Table 8. Readability Test Results

Aspects	Indicators	Scores obtained	Readability (%)	Category
Ease of use	Easy-to-use worksheets in the learning process	38	95	Very good
	Instructions for using the worksheet are clear and easy to understand	37	93	Very good
	The steps of activities in a worksheet are easy to follow	40	100	Very good
	The language used is simple and easy to understand	38	95	Very good
	The layout and design of the worksheet are interesting and not confusing	37	93	Very good
Time-effectiveness, benefits, and inquiry models	The allocation of time provided is by learning	38	95	Very good
	Worksheet helps streamline learning time	37	93	Very good
	Worksheet helps students understand concepts better	39	98	Very good
	Worksheet encourages students to learn independently	35	88	Very good
	Worksheet helps students improve their science process skills	37	93	Very good
PhET simulation integration	PhET simulation is easy to integrate into the learning	40	100	Very good
	PhET simulation helps visualize abstract concepts	39	98	Very good
	PhET simulation increases students' interest and motivation	40	100	Very good
	Instructions for using PhET simulation are clear and easy to follow	38	95	Very good
	PhET simulation helps us understand the concept of matter	39	98	Very good
		38	95	

PhET simulation supports data collection activities			Very good
Average readability test results	610	96	Very good

Table 8 shows the readability test results for ten grade 9 students. The average percentage of the readability test assessment for all aspects was 96%, with the category of very good without revision. This means that PhET simulation-integrated inquiry-based student worksheets are practically used in science learning in junior high school students.

To see the effectiveness of the student worksheets developed, a trial was carried out on 30 students in one class of the 9th grade, with a design model, namely one group pretest-postest design. Seeing the effectiveness of the worksheets developed to improve students' science process skills with N-gain. The results of the effectiveness of the worksheets developed to improve science process skills can be seen in Figure 5.

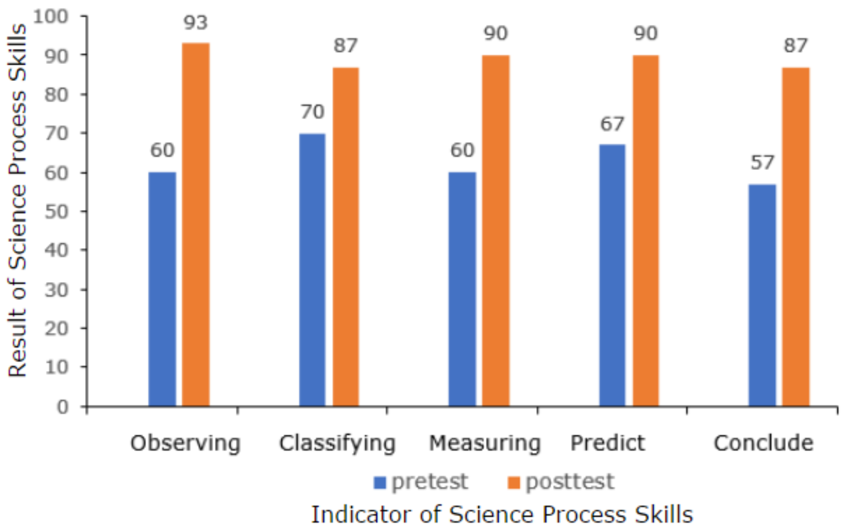

Figure 5. Pretest Posttest Scores Science Process Skills

The worksheets' effectiveness in enhancing science process skills can be evaluated using N-gain. Table 9 displays the N-gain values for each indicator of science process skills.

Table 10 N-Gain Score for Each Indicator of Science Process Skills

Aspects	Pretest	Posttest	N-gain	Criteria
Observing	60	93	0.83	High
Classifying	70	87	0.57	Medium
Measuring	60	90	0.75	High
Predict	67	90	0.7	Medium
Conclude	57	87	0.7	Medium
	Average N-gain		0.71	High

Table 10 presents the N-gain scores for science process skill indicators. The results demonstrate that the developed worksheets effectively enhance science process skills. This is evidenced by the average N-gain of 0.71 for science process skills, which falls into the high category. Consequently, the worksheet is an effective tool in science education for improving students' science process skills.

The final phase is dissemination. After the product's validation, readability, and effectiveness tests, the next stage is disseminating worksheets-based inquiry integrated with PhET simulation to schools that need them. These worksheets can be employed in scientific education to enhance students' abilities in conducting scientific procedures. The next activity is to make scientific papers related to the products developed. This research shows that PhET simulation integrated inquiry-based worksheets are feasible, practical, and effective for improving science process skills. There is previous research which improves science process skills, such as guided inquiry-based worksheets (Anisah & Nasrudin, 2023), using module-based inquiry (Yusra et al., 2021), using worksheets with assisted PhET (Arifullah et al., 2020), using PhET to learn science (Haryadi & Pujiastuti, 2020), using worksheets-based guided inquiry integrated PhET (Chotimah et al., 2023).

This research aligns with prior findings demonstrating that worksheets integrated by PhET simulations effectively improve scientific inquiry abilities (Novebrini et al., 2021; Rizki et al., 2022; Zulimah et al., 2018; Payudi et al., 2017), improve critical thinking skills (Rahmat et al., 2024), enhance educational achievements (Mahtari et al., 2020), PhET-assisted worksheets with STEM models enhance critical thinking skills (Agustina & Dwikoranto, 2021; Fitriyah & Madlazim, 2021), improve concept understanding (Wisnuputri et al., 2023), improve problem-solving skills (Kamila et al., 2021).

In addition, PhET also encourages active learning and inquiry and helps students develop problem-solving skills (Perkins et al., 2015; Sari et al., 2022). PhET implementation can enrich educational experiences by providing visual aids, practical demonstrations, and graphical representations (Makransky et al., 2019). In PhET, a visual display and interaction between students and the concepts being taught can help students develop an understanding (Price et al., 2018). PhET simulations are technological tools that enable students to visualise complex ideas, facilitating easier understanding and potentially boosting both academic performance and learning enthusiasm (Ganasen & Shamuganathan, 2017; Banda & Nzabahimana, 2023), as well as help teachers facilitate learning and contribute to learning (Peffer et al., 2015; Özcan et al., 2020), physics learning using PhET simulation can improve high-order thinking skills (Yusuf & Widyaningsih, 2019), learning using PhET assisted by a scaffolding approach can increase activity Learning (Eveline et al., 2019).

Conclusion

This research concludes that the validation results of the worksheets developed were obtained by Aiken's V 0.97 in the very high category. The results of the readability test were obtained with a percentage of 96% assessment in the very good and without revision category, and the results of the effectiveness test from the worksheets developed to improve science process skills were obtained with an N-gain of 0.71 with a high category.

This shows that PhET simulation integrated inquiry-based worksheets are feasible, practical, and effective in science learning to improve science processing skills.

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