Effect of Physics Inquiry Learning with Low-cost Experiment Tool on Students' Problem-solving Skills and Self-efficacy

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A R T I C L E   I N F O

A B S T R A C T

Students' low problem-solving skills and self-efficacy in physics learning significantly impact their overall learning processes and outcomes. An inquiry learning model and a low-cost experiment tool were implemented to address this issue. This learning model is designed to be valid and effective in enhancing students' problem-solving skills and self-efficacy. The research followed a non-equivalent control group design and involved 66 students to ensure the development of a high-quality learning model that meets the required standards and criteria. By utilizing learning instruments, such as students' response questionnaires, problem-solving pre-and post-tests, and self-efficacy questionnaires, the focus of the physics topic in this research was the simple mathematic pendulum. The validity test results show that the learning instrument has high validity and reliability criteria, making it feasible to use in physics learning. Furthermore, the statistical effectiveness test results show that this learning model effectively improves students' problem-solving skills and self-efficacy. As students engage in hands-on investigations and collaborate on meaningful projects, they are prompted to apply critical thinking and decision-making skills, directly contributing to developing effective problem-solving strategies. The intrinsic motivation derived from successfully navigating the challenges of inquiry learning, coupled with the personal relevance of the content, nurtures students' confidence in their abilities, ultimately strengthening their self-efficacy as independent and capable learners. Research implies the development of innovative learning models, effectively enhancing students' PSS and SE.

Introduction

Problem-solving skills (PSS) are the ability to identify, analyze, and solve problems effectively, involving critical thinking, creativity, and decision-making skills (Alsarayreh, 2023). PSS is essential in physics as it requires students to apply their knowledge to real-world situations (Supena et al., 2021), actualizing 21st-century skills (Saphira et al., 2022). Developing strong PSS can help students succeed academically and in their future careers. Self-efficacy (SE), on the other hand, is the belief in one's ability to succeed in specific situations or accomplish specific tasks. SE can also be crucial to academic success and personal development (J. A. Chen & Usher, 2013; Yilmaz & Lee, 2023). Students with high levels of SE are more likely to set challenging goals for themselves, work hard to achieve them, and persist in the face of setbacks (Hsu et al., 2023). So, the role of PSS is essential in the teaching and learning process.

PSS and SE have a strong relationship because the latter is essential in problem-solving and affects how individuals approach and respond to challenges (Psycharis & Kallia, 2017; Simamora et al., 2018).

Studies have shown that individuals with high SE are more likely to persist in problem-solving tasks, while those with low SE are likelier to give up or avoid challenges (Kurbanoglu, 2003; Ruch et al., 2022). Therefore, Improving PSS can help increase SE in students, leading to tremendous academic success and personal growth.

However, several references found that students' PSS and SE, particularly in science learning, are still low. For instance, students' PSS profiles tend to be low in some subjects, including general chemistry (Ijirana & Supriadi, 2018), general physics (Jua et al., 2018), general biology (Rahmawati et al., 2018), and impulse and momentum (Saifullah et al., 2017). Likewise, research by Kim et al. (2015), Putri & Prabawanto (2019), and Wulantri et al. (2020) confirmed that student's SE tends to be inadequate both in social and science subjects.

Another researcher discovered that metacognitive reflections can improve students' problem-solving skillfulness, indicating that students may need more support in developing their PSS and SE (Reinhard et al., 2022). Another study found that low-ability students have weaknesses in their cognitive levels, which can affect their ability to understand and solve problems and their learning motivation (Sepp et al., 2019). Thus, the low level of PSS and SE is an urgent problem that must be resolved immediately.

Implementing an inquiry learning model may be considered a viable solution to address the problem because the learning model is one success factor in the learning process. Some previous research investigated that collaborative-based inquiry learning effectively improves students' problem-solving skills (Herayanti et al., 2020), critical thinking skills (Nisa et al., 2018), and science process skills (Wijayaningputri et al., 2018). This is because students actively engage with the learning material instead of passively receiving information during inquiry-based activities.

Moreover, inquiry-based activities involve collaborative learning, where students work together to solve problems. Collaboration enhances their ability to approach and solve problems collectively and develops their sense of competence and contribution, boosting their self-efficacy. As students actively ask questions, conduct investigations, and seek solutions, they develop a sense of control and ownership over their learning experiences. A study confirmed that the inquiry learning model enhances students' SE (Sulistiyo & Wijaya, 2020).

However, in the inquiry learning process, it is necessary to have an experiment tool that can help students in undergoing the investigation process, one of which is the affordable or low-cost pendulum and collision prop (AOPC) (Prahani et al., 2023), as depicted in Figure 1. Generally speaking, to perform, for example, simple harmonic motion experiments, teachers and students need to develop sophisticated apparatus (e.g., Arduino-based) (Buachoom et al., 2019), so this may require higher costs. Hence, the distinction between AOPC and general learning tools lies in its cost-effectiveness and versatility. This experiment tool is versatile and can perform practical activities of damped oscillations, collisions, and simple mathematical pendulums. This tool has also been tested theoretically following relevant physics concepts. Additionally, the AOPC tool has also met the empirically valid and practical criteria, making it convenient for teachers and students to use in the learning process (Prahani et al., 2023). The reason for choosing simple harmonic motion and collision material is due to the tendency of students to experience misconceptions in these two materials because of the complexity of the material. (Janah et al., 2021; Kaniawati et al., 2021). The development of this practical learning tool is essential because it provides an affordable solution for schools, especially in rural areas, to implement effective learning processes without the high costs associated with traditional science learning media.

Figure 1
*AOPC Experiment Tool for Simple Math Pendulum Topic*
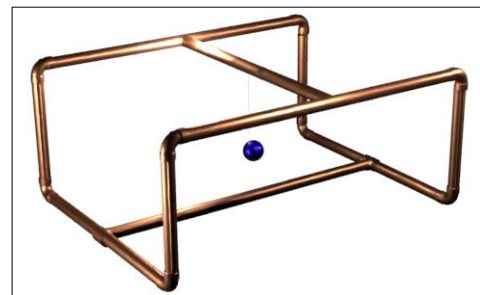
This research implements an inquiry learning model assisted by the AOPC tool to enhance students' PSS and SE, especially for physics learning. As a result, this study aims to investigate the validity and effectiveness of inquiry learning assisted with the AOPC tool in fostering students' PSS and SE. This study contributes to providing insight into integrating the inquiry model with AOPC to improve students' PSS and SE, which is the novelty of this study. This research is expected to improve the quality of education through innovative and sophisticated learning models.

Methods

This research uses a quantitative design with a quasi-experimental to achieve research objectives (Sugiyono, 2020). The feasibility of the product under implementation was tested through validation and limited trials to assess how inquiry learning assisted with the AOPC tool can enhance students' PSS and SE. The research was conducted between May and September 2022 at SMAN 3 Sidoarjo, Indonesia. The sample consisted of 66 students, with 33 in experimental and control classes. Random cluster sampling was utilized as the sampling technique, as the selection of sample groups followed instructions from the school administrator. The research stages are illustrated in Figure 2.

Figure 2
Research Stages
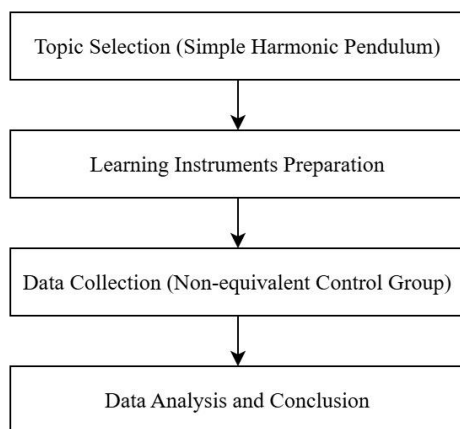
Learning instruments were assembled to support researchers in data collection and the learning process utilizing AOPC. Three experts in physics education evaluated these learning tools, and revisions and enhancements were implemented based on their recommendations. The subsequent step involves conducting limited trials on inquiry learning, assisted by the AOPC tool, to assess their effectiveness in enhancing students' PSS and SE. The research instruments in this study are outlined as follows.

1. Teaching modules contain syllabi and lesson plans. The learning model used is inquiry, where students will investigate simple mathematical pendulum material and AOPC-assisted collisions.
2. Teaching materials contain learning materials that students can learn independently. These materials become guidelines for them to direct all their activities in the learning process and form the substance of the formulated competencies.
3. Student worksheet contains tasks students must complete to create interactive AOPC-assisted learning.
4. The AOPC experiment tool was used as a learning prop to demonstrate experimental activities. This tool already has high validity, reliability, and practicality values, so it is suitable for use in physics teaching activities (Prahani et al., 2023).
5. Student questionnaires were used to determine their response to learning activities carried out by teachers using semantic differential scales.
6. Expert and practitioner questionnaires to gather their opinions on the validity and practicality of AOPC as a prop of science learning. The expert questionnaire also assesses the validity of other research instruments. This questionnaire was compiled using the Likert scale.
7. PSS test questions, adjusting the PSS rubric by Teodorescu et al. (2013), which include (A) Asses the problem; (C1) Create a drawing; (C2) Conceptualise the strategy; (E) Execute the solution; (S) Scrutinise the result. Each indicator consists of two questions according to the material supported by AOPC. This instrument is divided into two types, namely pre-test and post-test, so the increase in PSS can be known.
8. according to Bandura's (1997) dimensions, the academic SE questionnaire includes level, strength, and generality. Each dimension comprises 4-5 statements students must fill in using a semantic differential scale.

In terms of effectiveness, data was collected using a non-equivalent control group design involving two class groups (experimental and control) that experienced a pre-test and post-test (Creswell & Creswell, 2018). Initially, both classes were administered a pre-test for PSS. Subsequently, the experimental class received inquiry learning assisted with the AOPC tool through learning syntax consisting of (1) presenting the problem, (2) making hypotheses, (3) designing experiments, (4) conducting experiments, (5) analyzing data, and (6) making conclusions. Meanwhile, the control class followed conventional learning methods involving speeches, structured assignments, discussions, and question-and-answer sessions. The number of meetings, lesson hours, curriculum, instructors, and materials were identical for both classes. The material delivered focuses on a simple mathematical pendulum, aligning with the educational level of the sample and the school curriculum. After the lessons, both classes undertook the PSS post-test and completed the SE questionnaire. Only the experimental class filled out students' response questionnaires.

Table 1

Validity Criteria

Score	Criteria
$3.25 \leq V \leq 4.00$	Very Valid
$2.50 \leq V \leq 3.24$	Valid
$1.75 \leq V \leq 2.49$	Less Valid
$1.00 \leq V \leq 1.74$	Invalid

Descriptive analysis was performed on the learning instruments' validity data by averaging the values based on the standards given in Table 1 (Riduwan, 2012). Moreover, the corrected item-total correlation was used to evaluate the validity of the data statistically; according to Zijlmans et al. (2019), an instrument is deemed valid if its r_α value is greater than or equal to 0.4. Using a threshold of $\alpha \geq 0.7$ for the Cronbach Alpha value, the validity assessment also provided the foundation for evaluating the

instruments' reliability (Sugiyono, 2020). The choice of Cronbach Alpha was based on the consideration that it is widely accepted and reported across the literature.

Furthermore, analysis of the effectiveness of AOPC in improving PSS and SE students considers several indicators (Prahani et al., 2020): (1) the final grade of PSS is on medium criteria (50%); (2) the N-gain value of PSS is in the medium criteria (50%); (3) the PSS and SE effect size values are on medium criteria (50%); (4) there is a significant difference between the PSS pre-test and post-test; (5) there are significant differences in PSS and SE between the experimental class and the control class. The determination of PSS, N-gain, effect size, and student response values can be seen in Table 2 (Fritz et al., 2012; Hake, 1999; Limatahu et al., 2018).

Table 2

Criteria of PSS, N-gain, Effect Size, and Student Response

PSS Level		N-gain Criteria		Cohen's d-effect		Students Response	
Score	Criteria	Score	Criteria	Score	Criteria	Percentage (%)	Criteria
$0 \leq PSS \leq 2.3$	Low	< 0.3	Low	0.2	Small	$R < 25$	Not Positive
$2.4 \leq PSS \leq 4.7$	Medium	$0.3 \leq g < 0.7$	Medium	0.5	Medium	$25 \leq R < 50$	Less Positive
$4.8 \leq PSS \leq 7.0$	High	≥ 0.7	High	0.8	Large	$50 \leq R < 75$	Positive
						$R \geq 75$	Very Positive

Result and Discussions

Validity of Learning Instruments

As shown in Table 3, expert validity was selected to evaluate the learning instruments' viability. Each instrument's constructs and content are the focus of validity. All instruments, the learning module, teaching materials, student worksheet, test

instrument, and student questionnaire are valid and reliable overall. This shows that inquiry learning assisted with the AOPC tool can measure the targeted constructs accurately and consistently, making them suitable for the research project. After some minor adjustments, experts say the instruments are ready for use. After a few minor adjustments, the instruments can be evaluated for usefulness and efficacy in raising students' PSS and SE.

Table 3

Learning Instruments Validity Assessment

Instruments	Validity Score		r_α	Validity Criteria	α	Reliability
	Content	Construct				
Learning Module	3.50	3.67	1.00	Very Valid	0,97	Reliable
Teaching Material	3.67	3.50	0.92	Very Valid	0.82	Reliable
Student's Worksheet	3.56	3.50	1.00	Very Valid	0.72	Reliable
PSS Test Instrument	3.67	3.67	0.87	Very Valid	0.73	Reliable
Student's Questionnaire	3.58	3.67	0.92	Very Valid	0.87	Reliable

When valid learning instruments are used, students' PSS and SE can be measured with accuracy, enhancing the research findings' reliability and validity. Reliable assessment instruments also assist teachers in making defensible judgments regarding the performance and advancement of their students. Valid learning instruments can provide students' learning outcomes with a sense of completion and

improve their comprehension of physics concepts, according to research findings by (Annur et al., 2019; Wibowo et al., 2023).

Effectiveness of Learning Activity

Table 4 shows an increase in problem-solving test scores in both groups, where the experimental group

has a high final average, while the control group has a medium criterion. The results of the prerequisite test show that the data are typically distributed and homogeneous, so parametric statistics are used. So, this study used a paired t-test and found significant differences between the pre-and post-test groups. Furthermore, Table 5 shows that the independent t-test between the post-test experimental and control groups showed substantial differences. This finding corroborates previous differences that although there were significant differences between pre-test and post-test in the two groups, post-test scores between the two groups were also significantly different.

The analysis continued by calculating both classes' effect size and N-gain value, as in Table 6. It can be seen that Cohen's d value has a vast criterion, suggesting that the implementation of inquiry learning assisted with the AOPC tool has a highly significant influence on the students' PSS. This effect size highlights the effectiveness and potency of using the learning model as an intervention in the experimental group. Regarding N-gain, the experiment class experienced a higher improvement or learning gain than the control class with conventional learning. This is reinforced by the result of the independent sample t-test between the variance of the experimental group's N-gain with the control that there is a significant difference.

Table 4
Descriptive and Paired Sample t-test of Students' PSS

Group	N	Pre-test			Post-test			p-value
		M	SD	Criteria	M	SD	Criteria	
Experiment	33	2.73	1.26	Medium	5.61	0.52	High	0.00*
Control	33	2.52	0.95	Medium	3.85	0.45	Medium	0.00*

*$p < 0.05$

Table 5
The Independent Sample t-test of students' PSS post-test

Group	N	Mean	SD	Criteria	t	p-value
Experiment	33	5.61	0.52	High	14.34	0.00*
Control	33	3.85	0.45	Medium		

*$p < 0.05$

Table 6
PSS Effect Size, N-gain, and Independent t-test of N-gain

Group	N	Effect Size		N-gain		p-value
		Cohen's d	Criteria	Mean	Criteria	
Experiment	33	2.71	Very Large	0.66	Medium	0.00*
Control	33			0.28	Low	

*$p < 0.05$

These results suggest that using inquiry learning assisted with the AOPC tool in the experiment class led to a significantly more significant improvement in learning outcomes than the control class with conventional learning. The combination of large effect size and higher N-gain in the experiment class supports the effectiveness and impact of the learning model in enhancing student learning compared to traditional instructional methods. This is because students conduct the investigation process, applying theoretical concepts and principles to real-world scenarios to promote a deeper understanding of physics concepts. Through experiments on simple mathematical pendulums, students can develop critical thinking skills, analyze data, and draw meaningful conclusions (Sutiani et al., 2021). This process fosters their problem-solving abilities and enhances their scientific inquiry skills (Frey et al., 2022).

These findings align with research by Wibowo et al. (2023) that physics learning props can attract students interested in physics learning, help the learning process, and increase students' understanding of concepts in the material taught. Research by Matsun

et al. (2021) confirmed that using props in physics learning could improve students' higher-order thinking skills through hands-on practical experience. Another research by Haryadi et al. (2019) is also consistent with this study that physics learning props can effectively improve students' science process skills because they can visualize the material that it is so that students are more interested, concerned, and more focused in learning and make the students more easily understand information.

Implementing AOPC in learning science or physics is strengthened by social constructivism learning theory (Schunk, 2011). Inquiry learning assisted with the AOPC tool can be used in collaborative learning settings, where students work together to explore and solve science or physics problems using the prop. Through group discussions, peer interactions, and shared problem-solving processes, students can construct knowledge collaboratively, develop communication skills, and enhance their problem-solving abilities (S.-Y. Chen et al., 2021; Gu et al.,

2015). What is more, inquiry learning assisted with the AOPC tool aligns with the principles of experiential learning, where students actively engage in concrete experiences, reflect on those experiences, conceptualize new knowledge, and apply it in problem-solving contexts (Kolb, 2014). The learning model provides students hands-on opportunities to manipulate and observe the science and physics principles related to collisions and pendulums, enhancing their problem-solving skills through practical application.

Regarding SE, Table 9 presents the mean, effect size, and results of the Mann-Whitney U test after students have gone through the learning process. Non-parametric statistics are used because the data do not meet the normal and homogeneous prerequisite criteria. However, it can be seen that the mean value in the experimental group is greater than that of the control group, with the effect size being in the medium criterion. In addition, there were significant differences in student SE between both classes.

Table 7
Mean, Effect Size, and Mann-Whitney U Test of Students' SE

Group	N	M	SD	Effect Size		Mann Whitney U	
				Cohen's d	Criteria	U	p-value
Experiment	33	84.09	13.69	0.62	Medium	228.5	0.02*
Control	33	76.33	10.94				

*$p < 0.05$

The use of inquiry learning assisted with the AOPC tool in the experimental group tends to provide students with tangible experiences and opportunities to actively engage in science and physics experiments related to collisions and pendulums. Through these experiences, students may have gained a better understanding of the concepts, developed problem-solving skills, and improved their confidence in applying their knowledge to real-world situations (Turan & Matteson, 2020). This experiential learning approach can enhance self-efficacy by allowing students to witness successes and build competence in physics problem-solving tasks (Watters et al., 2015). Additionally, through inquiry learning aided by AOPC, students had the opportunity to observe and learn from their peers' experiences and successes with the AOPC. This vicarious learning can influence students' self-efficacy by providing role models and demonstrating that others can succeed in science problem-solving tasks (Kozar et al., 2015).

From a theoretical perspective, SE is a central construct in social cognitive theory, proposed by Albert Bandura (Bandura, 1997). According to his theory, individuals' beliefs in their capabilities to

successfully perform specific tasks (such as problem-solving in science) play a crucial role in their motivation, performance, and achievement. The higher self-efficacy observed in the experimental group suggests that the AOPC may have enhanced students' confidence and belief in their ability to engage effectively in science problem-solving tasks (Shen et al., 2016).

Therefore, collectively, students' PSS and SE were trained through syntax during the inquiry learning process, which included presenting the problem, making hypotheses, designing experiments, conducting experiments, analyzing data, and making conclusions. Among the six steps, "conducting experiments" most influences the enhancement of students' PSS and SE. This step requires students to apply their theoretical knowledge practically, navigate unforeseen challenges, and test their hypotheses, thereby directly engaging in solving complex problems (Schunk, 2011). Moreover, successfully carrying out experiments, observing tangible results, and overcoming experimental hurdles build students' confidence in their ability to manage and complete

tasks effectively, significantly boosting their self-efficacy.

Based on each PSS and SE indicators analysis, the inquiry learning steps require students to engage deeply with the problem, from assessing it and creating visual representations to conceptualizing strategies, executing solutions, and scrutinizing results. These activities collectively enhance critical thinking, strategic planning, and reflective evaluation, strengthening students' PSS (S.-Y. Chen et al., 2021). Moreover, successfully carrying out experiments, particularly those that are complex, boosts students' confidence in their abilities (level), reinforces their belief in their competence (strength), and highlights the applicability of their skills across different contexts (generality) (Turan & Matteson, 2020). As a result, conducting experiments hones practical problem-solving skills and significantly enhances self-efficacy by building a robust and transferable sense of capability.

Table 8 represents student responses to inquiry learning assisted with the AOPC tool. The findings show that they respond positively to the learning process. Most of the students agreed with statements related to the effectiveness of the learning model in enhancing their problem-solving abilities, applying concepts to everyday problems, and analyzing experimental results in the context of materials that have been taught. This suggests that the hands-on experience provided by the learning model is beneficial for students' understanding and application of science concepts.

Table 8
Students Response

Question Number (%)							Average (%)	Criteria
1	2	3	4	5	6	7		
71.82	71.21	71.52	73.33	79.09	77.88	77.88	74.68	Positive

Furthermore, the survey results indicate that most students found the simple math pendulum material more accessible after using inquiry learning assisted with the AOPC tool. This suggests that the hands-on approach facilitated by AOPC helped students grasp the concepts more effectively than traditional teaching methods alone. This finding is consistent with Suryani et al. (2021) research, in which learning media that get positive responses effectively improve student learning outcomes and SE.

Figure 3
Inquiry Learning Process using the AOPC Tool

Ultimately, the student's desire to further develop inquiry learning assisted with the AOPC tool for other science materials indicates their positive perception and endorsement of the prop as a valuable teaching aid (Figure 3). This feedback provides insights for future improvements and adaptations of inquiry learning assisted with the AOPC tool to cater to a broader range of science topics and experiments.

Conclusions

Physics learning with inquiry learning is assisted by the AOPC tool, demonstrating the strong validity and reliability of the learning instruments. The effectiveness tests conducted on the learning model reveal its significant impact in improving students' PSS and SE, as evidenced by considerable N-gain and effect size. Moreover, students have responded positively to inquiry learning assisted with the AOPC. Inquiry and AOPC-based learning model empowers students by providing opportunities for active engagement, decision-making, and success through exploration and problem-solving, especially in physics: a simple mathematical pendulum topic. These experiences contribute to the development of self-efficacy, fostering a belief in their abilities to tackle challenges and achieve success in their academic pursuits and beyond.

Limitation, Recommendation, and Implications

This research is limited to simple mathematical pendulum material and high school level; hence, the recommendation is to test on other materials and educational levels. Finally, the research object focuses on PSS and SE and, as a follow-up, can explore skills that can potentially improve. The implications of this research are particularly relevant for developing innovative learning models, especially in rural areas, where they can effectively enhance students' PSS and SE.

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