JPPIPA 11(10) (2025)

Jurnal Penelitian Pendidikan IPA

http://jppipa.unram.ac.id/index.php/jppipa/index

Enhancing Higher Order Thinking Skills and Scientific Attitudes Through Arduino-Based Experiments

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Received: August 31, 2025
Revised: September 28, 2025
Accepted: October 25, 2025
Published: October 31, 2025

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DOI: 10.29303/jppipa.v11i10.12700

Abstract: In science learning, students' higher-order thinking skills (HOTS) and scientific attitudes are still low. Problems become increasingly complex when the COVID-19 pandemic minimally transforms students' interactions with their community environment. Innovation is needed to obtain an experimental model integrated with the Arduino Internet of Things to enhance HOTS and scientific attitudes. This research aims to obtain a valid and practical Arduino-based experiment model and its effect on HOTS and scientific attitudes. This research and development refers to Borg and Gall consisting of research and collecting of information, planning, initial product development, initial testing, main product revision, main field testing, operational product revision, operational field testing, final product revision, and dissemination. The research subjects involved were physics lecturers, education practitioners, and physics education students in West Kalimantan, Indonesia. Enhancing HOTS after implementing an experiment is calculated using the Multivariate Analysis of Variance. The arduino based experiments model has proven feasible, practical, and effectively applied to improve students' HOTS and scientific attitudes. The results become an innovative alternative laboratory work model to be used as a policy recommendation in higher education.

Keywords: Arduino; Experiment; HOTS; Scientific attitudes

Introduction

The fourth Sustainable Development Goal (SDG) specifically addresses education want inclusive, quality, lifelong education fairly and equitably. Anticipatory thinking skills, collaboration, problem-solving, self-awareness, and normativeness competence must be realized to achieve the SDGs of quality education (UNESCO, 2017). The demands of the industrial revolution, which is currently being promoted at stage 4.0 will be met if every individual is caring, responsible, able to think, has character, respects each other, and is critical (Gleason, 2018). This foundation shows that it is important for students to master attitudes and thinking skills. The COVID-19 pandemic has minimally transformed students' interactions with their environment. As a result, higher-order thinking skills (HOTS) do not develop optimally. Research has shown the problem of low scientific attitudes and HOTS (Maharani et al., 2021; Oh, 2025). Evidence of low scientific attitudes is that 18.5% and 61.5% of international students have low and medium scientific attitudes (Paul & Kumari, 2020). Forty students in conventional laboratories in Indonesia scored 39 (Ikhsan, Astuti, & Sugiyarto, 2020), and 58% of students in Pontianak City have a low scientific attitude (Hadiati et al., 2019). Facts about students' low HOTS include: 58% of students have low HOTS (Husamah et al., 2018), 35% of international level students did not experience an increase in HOTS after learning (Keleman et al., 2021),

How to Cite:
Saputri, D. F., Pramuda, A., Hadiati, S., Fadillah, S., Kurniawan, E. S., & Matsun. (2025). Enhancing Higher Order Thinking Skills and Scientific Attitudes Through Arduino-Based Experiments. *Jurnal Penelitian Pendidikan IPA*, *11*(10), 8–15. https://doi.org/10.29303/jppipa.v11i10.12700

41.2% of participants had low HOTS (Widyaningsih et al., 2021). This shows that scientific attitudes and HOTS need to be improved.

The experiment is proven to increase students' HOTS with a score of 86 (Widyaningsih et al., 2021). The development of laboratory experimentation improves the scientific attitude with an n gain of 0.4 (Hadiati et al., 2019). Visualization can improve critical thinking skills (Ikhsan et al., 2020). Physics Laboratory Work with Arduino can improve 21st-Century Competence (Hadiati et al., 2019; Fajrina et al., 2020). Arduino-based laboratory work can enhance HOTS and scientific attitude (Omar & Awang, 2023). Laboratory science environment learning was a predictor of HOTS (Omar & Awang, 2023). Laboratory Work Style with Arduino improves the critical attitude (Hadiati et al., 2019). Adapting to new habits opens up opportunities for online and offline learning, so laboratory experimentation models using Arduino need to be optimized.

The use of Arduino for laboratory experimentation models (laboratory work) is determining the coefficient of kinetic friction (Coban, 2020), light sensors (Kinchin, 2020), and investigating Newton's Second Law (Bien & Hai, 2019) and parking information system (Hayati et al., 2024). The weakness of this research is that the Arduino device was developed only as a measuring tool, which is not yet based on the Internet of Things (IoT). Other research is related to Arduino experimental equipment, namely polarization and magnetic field experimental devices for remote laboratories (Ishafit et al., 2019; Ishafit et al., 2020; Martin et al., 2021). The weakness of this research is that students only control measuring instruments and receive data remotely, not accommodating the development of HOTS optimally. Another crucial weakness is that students do not develop their capacity, character, and values in line with their contribution to society (Gross & Rutland, 2017). Therefore, it is necessary to develop experiments integrated with Arduino IoT to enhance students' HOTS and scientific attitudes toward the SDGs of quality education (Kurelovic et al., 2020).

Method

The research and development used in reference to Borg and Gall consists of ten steps, mentioned as follows: research and collecting of information, planning, initial development, initial field test, main product revision, main field test, operational product revision, operational field test, final product revision, and dissemination (Gall et al., 1996). This research will be conducted in West Kalimantan, Indonesia. The research subjects involved in the research were lecturers, education practitioners, and students of the Physics Education Study Program at PGRI University Pontianak (García-Tudela & Marín-Marín, 2023; Marín-Marín et al., 2024). The students were selected using a cluster random sampling technique. A total of 70 students were divided into two groups: A and B. Group A was taught using ordinary experiments. Group B with Arduino experiments.

The validation sheet is used to assess the feasibility of the Arduino based experiment model. The observation sheet is used to assess the implementation of the Ardino based experiment model. The practicality of the Arduino based experiment model is measured by the implementation of the experiment. The students' HOTS is measured using a test. The HOTS test consists of three indicators, namely analysis, evaluation, and creation skills. Based on content validity, the HOTS test used was characterized by a validity value of 0.82, which falls into the high category, and a reliability of 67%. Another characteristic related to its empirical validity value indicates that the HOTS test used was categorized as valid (0.99) and had an item reliability of 0.89 and person reliability of 0.48 in the good and medium categories. The scientific attitude questionnaire is equipped with multilevel answer choices with indicators of curiosity, cooperation, and critical attitude. Based on its content validity characteristics, the scientific attitude test used had a validity value of 0.81, which is in the high category, and a reliability of 80%. Empirical validity characteristics indicate that the HOTS assessment used fell into the valid category (0.96), and the reliability of the test items reached 0.93 and person reliability of 0.39 in the good and medium categories.

The feasibility and practicality of the product were tested by seven validators, consisting of material experts, media experts, and language experts with Aiken Indeks. Enhancing HOTS after implementing a hybrid experiment is calculated using a Multivariate Analysis of Variance (MANOVA). Normality, homogeneity, and Box M tests were carried out as a prerequisite for analysis in this research. The normality test used in the preliminary analysis was the Kolmogorov-Smirnov test. Another preliminary analysis, namely the homogeneity of the samples used, was tested using the Levene test method.

Result and Discussion

Results

Planning Stage

This planning stage is the construction of an Arduino-based experiment designed to involve students in practical activities using the grand theory of experiential learning with modifications to the reasoning-based comprehensive laboratory work model. This comprehensive model is a combination of deductive models, problem-solving, and engineering skills (Maryatiab et al., 2022; Lee, 2020; Nguyen et al., 2024). This Arduino-based hybrid experiment, through the learning stages in, will make students play a direct role in the study of appropriate technology in society, which ultimately improves HOTS. The schematic of the Arduino-based experiment is presented in the Figure 1.

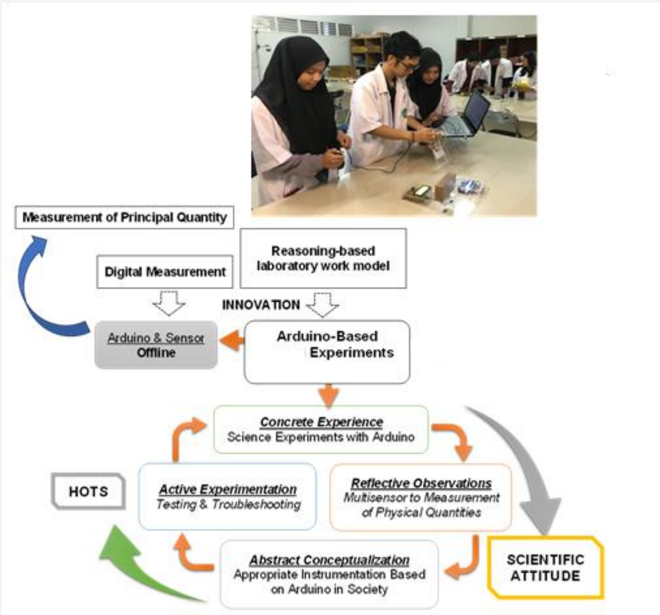

Figure 1. The Arduino-based experiment model

Reviewing Figure 1 This model is a more comprehensive model because it combines the advantages of the reasoning-based laboratory work model with two forms of using Arduino for measurements with Arduino sensor modules. Learning takes place through four phases with reflection in each cycle, namely experiences presented concretely, observations carried out reflectively, conceptualization abstractly, and experiments carried out actively. This phase refers to the experiential learning phase of Kolb's model. In the concrete experience phase, science experiments are carried out with Arduino; students not only learn about the subject material studied in basic physics but are also introduced to how to use Arduino sensors to measure basic quantities in physics and observe the measurement results directly from the LCD display or Arduino IDE serial print (Kranz et al., 2023). Students also introduced how to use Arduino sensors to measure basic quantities in physics connected to IoT. In this phase, students' curiosity is sought to be increased. In the reflective observation phase, apart from defining and deriving other physical quantities that are in line with the material, students are invited to develop instruments through multisensory measurements of physical quantities. In this phase, students' critical thinking is facilitated. In the abstract conceptualization phase, students analyze problems in everyday life to produce appropriate technology. For example, in reviewing Figure 1, students found that temperature affects the viscosity of liquids, and this is important in determining the quality of oil for cooking food, so a viscometer is needed as a solution (Sari & Kirindi, 2019). In this phase, there must be critical thinking and collaboration between students so that the technology completion time can be effective. In the active experimentation phase, students develop their abilities in carrying out testing and troubleshooting, for example testing smart stove products and electrical circuits (Cloutier et al., 2016). In this phase, aspects of student curiosity, critical thinking, and collaboration are more comprehensive. It is clear that the uniqueness of this model and its phases is that it encourages the formation of a scientific attitude, which includes aspects of curiosity, critical thinking, and collaboration.

Initial Product Development Stage

Activities at the initial product development stage, namely student observations in experiments to determine reasoning steps that can improve HOTS and scientific attitudes. Learning support devices were also prepared (practicum guides equipped with experimental tools based on Arduino).

Initial Field Test Stage

In the initial field test stage, validation of the Arduino-based experiment and its supporting devices, namely Expriment guides and experimental tools, was carried out with experts. Model testing is needed to ensure that the Arduino-based experiment model is suitable for application in laboratory work (Riwandi et al., 2025). The Arduino-based experiment model is as in Figure 1. Testing was carried out by three people, namely a learning media expert and a physics material expert. The assessment results are presented in Table 1.

Table 1. Calculations of the Feasibility of the Model and its Supporting Tools from Experts

Instruments	Validity	Criteria
Arduino-based Experiment Model	4.30	Good
Experimental tools	4.57	Very Good
Experiment Guides	4.56	Very Good

Table 1 shows the results of calculations of the feasibility of the model and its supporting tools from experts. The calculation results show that the Arduino-based experiment model is valid in the high category, so it can be concluded that the Arduino-based experiment model is suitable for use.

Main Field Test Stage

In the Main Field Test, the practicality of the model was measured by lecturers and education practitioners. Each meeting has six stages that must be carried out, namely formulating objectives, reviewing theory, designing experiments, conducting experiments, troubleshooting, and concluding. Three observers carried out the implementation assessment. The observation sheet for the implementation of the Arduino-based experiment model uses a dichotomous assessment, namely scores 1 and 0. A score of 1 is given if the indicator is implemented a score of 0 if it is not implemented. Table 2 shows the implementation of the Arduino-based Experiment model. The following table shows that the Arduino-based hybrid experiment model is good to use so that it meets the practicality criteria.

Table 2. Implementation of the Arduino-based Hybrid Experiment Model

Fase	Meeting 1			Meeting 2		
	1	2	3	1	2	3
Theory Guide Study	1	1	1	1	1	1
Technical Formulation	1	1	1	1	1	1
Experiment	1	1	0	1	1	0
Problem Description	0	0	1	0	0	1
Cause Analysis	0	0	0	0	0	0
Repair and Revision	0	0	1	1	1	1
Evaluation	1	1	1	1	1	1
Conclusion	1	1	1	1	1	1
Average			5.5			6
Criteria			Good			Good

Operational Field Test Stage

At the Operational Field Test Stage, the model and equipment were tested on students. The Arduino-based experiment model was implemented in laboratory work, and its effectiveness on HOTS and also scientific attitude was tested. The effectiveness of the model is determined by testing significant differences in HOTS and also scientific attitude. Normality test, homogeneity test, and Box Test Results for Similarity of Covariance Matrices were carried out as prerequisite tests for analysis shown on Tabel 3-5. The data of Normality, Homogeneity, and Box M shows that all data has a sig value > 0.05, so it can be concluded that all data is normally distributed and homogeneous; therefore a parametric test was carried out with MANOVA on Table 6.

Table 3. Normality Test Results

Data	Class	Kolmogorov-Smirnov			Shapiro-Wilk			Decision
		Statistic	df	Sig.	Statistic	df	Sig.	
HOTS	Ordinary	0.133	35	0.122	0.957	35	0.187	Normal
	Arduino	0.135	35	0.108	0.945	35	0.080	Normal
Scientific Attitudes	Ordinary	0.125	35	0.180	0.956	35	0.173	Normal
	Arduino	0.128	35	0.160	0.959	35	0.207	Normal

Table 4. Homogeneity Test Results

Data	Levene's Test				Decision
	F	df1	df2	Sig	
HOTS	0.042	1	68	0.838	Homogenous
Scientific Attitudes	0.007	1	68	0.933	Homogenous

Table 5. Box Test Results for Similarity of Covariance Matrices

Data	Levene's Test				
	Box's M	F	df1	df2	Sig
HOTS & Scientific Attitudes	0.188	0.061	3	832320.000	0.980

Table 6. MANOVA Test Results

Test	Value	F	Hypothesis (df)	Error (df)	Sig.
Pillai's Trace	0.814	146.169	2.000	67.000	0.000
Wilks' Lambda	0.186	146.169	2.000	67.000	0.000
Hotelling's Trace	4.363	146.169	2.000	67.000	0.000
Roy's Largest Root	4.363	146.169	2.000	67.000	0.000

The summary table of MANOVA test results shows that the sig value is <0.05, so there is a significant difference in HOTS and scientific attitudes between the experimental and control classes. The increase in scientific attitude and HOTS after learning will be determined by calculating the gain. The magnitude of the increase in scientific attitudes and HOTS is presented in Figure 2.

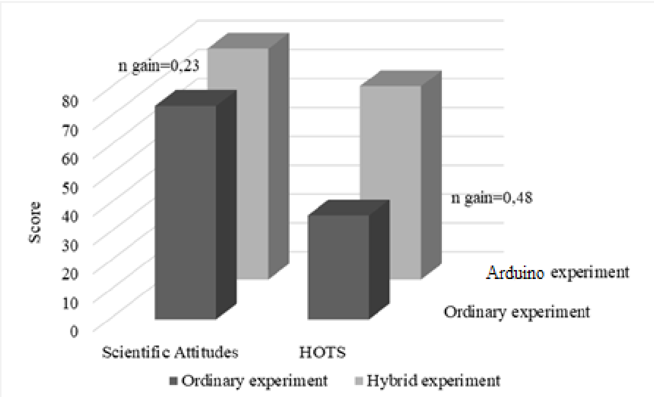

Figure 2. Enhancing HOTS and scientific attitudes after implementing Arduino-based experiment

Figure 2 shows an increase in HOTS and scientific attitudes after implementing the Arduino-based experiment. Scientific attitudes increased in the weak category, while HOTS increased in the moderate category. This shows that learning with Arduino-based experiment can significantly improve scientific attitudes and HOTS.

Discussion

The Arduino-based experiment model that has been developed is a new laboratory work model based on the use of Arduino digital technology as a measurement model so that it can encourage knowledge formation. This Arduino-based experimental model directs students to form experiences through interaction with the environment. This learning is in line with experiential theory to stimulate students in their activities of thinking, exploring, asking questions, making decisions, and applying what they have learned (Syurygin et al., 2022).

The Arduino-based experimental model directs learning through a cycle of experiences involving environmental contact and communication to generate thinking abilities. The learning model has quite a significant influence towards the increment of students' HOTS (Maryani et al., 2022). Lecturers are expected to be able to encourage their students to be able to behave scientifically (scientific attitude) through investigative activities (Adiansyah et al., 2021).

The Arduino-based experiment model presents experiments in small groups using Arduino so that it can emphasize the process of thinking and reasoning as problem-solving. Learning Robotics using an Arduino refer to the Kolb model increases the ability to fix up real-world problems (Ibrahim, et al., 2020). The process of thinking and learning as problem-solving is directed at collaborative learning (Heijnes & Van, 2018).

The use of digital technology as an important process in the Experimental model is very appropriate and in sync with the cognitive development of students who have reached the stage of being able to think to solve complex problems that are no longer in the form of real objects but more abstract (Wysocki et al., 2013). This is in accordance with the theory of cognitive development, which shows that students as prospective teacher students who are involved, at this age should be able to think logically and abstractly so that they are able to think multidimensional in finding solutions or solving a problem (Malone et al., 2018). Students have a self-concept that is formed according to the stages of cognitive development at their age to be able to find various alternative solutions and solve problems effectively.

The results of assessments from experts regarding the suitability of the Arduino-based experiment model and learning tools show that the Arduino-based Experiment model and tools developed are appropriate to facilitate the characteristics of students' and the complexity of physics material to improve HOTS and also students' scientific attitudes. The Arduino-based hybrid experiment model using Arduino can present a measurement model that can encourage students' reasoning skills, thereby further encouraging their HOTS and scientific attitudes. Students' reasoning is stimulated and encouraged by presenting various new methods of measuring physical quantities, modeling activities, and innovative and engaging activity guides (Malone et al., 2018).

The combination of various digital guides and sensor technologies makes it possible to effectively implement laboratory work in physics and mmechatronics disciplines in a learning activity format that is highly flexible and accessible (Syurygin, Deryagin et al., 2022). Modeling using affordable and up-to-date physical measuring instruments helps students process scientific information and develop it more meaningfully. Using Arduino, supported by sensors appropriate for physics, to implement measurement models can stimulate students' reasoning during practical activities.

This equipment operates in harmony with the development of logic-creating skills. There is a balance between the code created and the skills required to modify or assemble sensors with various supporting systems and perform measurements.

The Arduino-based experimental model has proven effective in encouraging the positive development of HOTS and students' scientific attitudes. This is evident from the results of the model's implementation. Initial results from the implementation assessment in each activity session met the Very Good criteria. Students preferred practicums as an alternative learning method. The laboratory practice model demonstrated significantly helped students gain empirical understanding and skills. This indicates that the Arduino-based hybrid experimental model can be well adopted in learning and can help students achieve competency.

Conclusion

The Arduino-based experimental model has been able to present its feasibility, practicality, and effectiveness in positively developing students' HOTS. The Arduino-based experiment model will be an accelerator towards achieving SDGs quality education through low-cost learning technology to facilitate personalized and exploratory learning and help realize quality learning in marginalized areas. The Arduino-based experimental model has become an alternative innovative laboratory work model that can be considered as an innovative policy recommendation in higher education institutions that educate prospective teachers to improve the main competencies of their graduates in the form of being able to plan, implement, and assess HOTS-oriented learning, utilizing various learning resources and science and technology-based media, as well as the potential of technology that is developing in the region in line with process and quality standards. In addition, competencies in the form of mastering theories, scientific methods and scientific attitudes to integrate physics concepts and develop forms of physics experiments that are in line with the implementation of various educational theories to support the competencies of prospective physics teachers, namely measurement techniques specifically utilizing Arduino and related IoT technology.

Acknowledgments
With gratitude, the author expresses his gratitude to all parties who have provided support in the preparation of this work. In particular, he expresses his gratitude to PGRI University Pontianak.

Author Contributions
Conceptualization, writing—original draft preparation, resources, Adi Pramuda; investigation, supervision, visualization, Dwi Fajar Saputri; methodology, data curation, Soka Hadiati; validation, project administration, Syarifah Fadillah; writing—review and editing, Eko Setyadi Kurniawan and Matsun.; All authors have read and agreed to the published version of the manuscript.

Funding
This research is supported by a DRTPM, DITJEN DIKTIRISTEK, KEMDIKBUDRISTEK with grand number 44/L.11/KM/2025.

Conflicts of Interest
The authors declare that there is no conflict of interest that could affect the objectivity, integrity, or results of this research. The entire data collection, analysis, and report preparation process was conducted independently without any influence from third parties, sponsors, or institutions with financial or non-financial interests in the research results.

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