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Development of Water Quality Measurement Tools to Improve High School Students' Scientific Reasoning Through Water Pollution Investigation

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Abstract

The low level of scientific reasoning skills among 10th grade high school students on the subject of water pollution shows the need for learning innovations that can integrate investigative activities based on real data. Learning that is still predominantly conceptual does not fully involve students in the process of measuring, collecting, and analyzing data directly. Therefore, learning media that allows students to conduct authentic scientific investigations is needed. The Arduino-based water quality measurement system offers advantages in the form of real-time data presentation, portability, and the possibility of integrating the experimental process and data analysis in one learning device. This study aims to (1) determine the feasibility of Arduino-based water quality measuring devices, (2) measure the improvement in the scientific reasoning abilities of 10th grade high school students, and (3) determine student responses to the use of teaching aids in the Problem-Based Learning (PBL) model. This study is a research and development (R&D) study using the ADDIE model (Analysis, Design, Development, Implementation, and Evaluation). The trial was conducted using a one-group pretest-posttest design. The research instruments included expert validation sheets, scientific reasoning tests, and student response questionnaires. The data were analyzed descriptively and quantitatively, while the improvement in ability was analyzed using N-Gain scores. The results of validation by two physics education lecturers and one high school teacher showed an average feasibility score of 96.53% (very feasible). The N-Gain test results showed a significant improvement with an average score from 36.46 to 89.47 and an N-Gain value of 0.83 (high category). All scientific reasoning indicators experienced a high increase, and student responses reached 98.61% (very good). The Arduino-based water quality measuring device developed was declared highly feasible and effective in improving the scientific reasoning skills of 10th grade students on the subject of water pollution.

Keyword: *ADDIE; Problem-Based Learning; Water quality teaching aids; Scientific reasoning; Water pollution investigation.*

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1. INTRODUCTION

Water pollution in Indonesia remains a serious environmental problem, both in urban and rural areas. Rapid population growth and increased industrial and domestic activities have led to an increase in the discharge of liquid waste into water bodies without adequate treatment. This condition has a direct impact on environmental quality and public health, such as an increased risk of diarrhea, skin infections, and other health problems (Kautsar et al., 2021). River pollution caused by poorly managed domestic, industrial, and agricultural waste is a persistent problem that threatens aquatic ecosystems and reduces the quality of human life (Abdi et al., 2024).

Based on Regulation of the Minister of Health of the Republic of Indonesia Number 49/MENKES/PER/2010, water quality is determined by three main parameters, namely physical, chemical, and biological parameters. Physical parameters include turbidity, temperature, color, taste, odor, and total dissolved solids. Chemical parameters include pH, Dissolved Oxygen (DO), Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), nitrate, nitrite, sulfate, hardness, and dissolved metals. Biological parameters include Total Coliform and Escherichia coli. These three parameters are interrelated and together determine the level of water suitability. Physical parameters such as temperature and turbidity are related to chemical parameters, including pH. Changes in temperature can affect the rate of chemical reactions and the solubility of substances in water, while turbidity can indicate the presence of suspended particles that have the potential to disrupt the chemical balance of water. Thus, understanding water quality requires an approach that scientifically integrates the relationships between these parameters.

Data from the Ministry of Environment cited by Nasution et al. (2022), shows that around 75% of rivers in Indonesia are polluted. This fact indicates that water quality issues are at an alarming level and require serious attention. This condition also indicates that the environmental literacy of the community, including students, still needs to be improved through education. Education plays a strategic role in fostering students' awareness and scientific thinking skills regarding environmental issues. One important skill in science learning is scientific reasoning, which includes the ability to formulate hypotheses, control variables, design experiments, analyze data, and draw conclusions based on empirical evidence (Syofyan, 2023). Developing these skills requires a learning model that provides students with opportunities to conduct direct investigations.

The Problem-Based Learning (PBL) model is one effective approach to developing scientific reasoning. Through PBL, students are presented with contextual problems that require a systematic process of investigation, data collection, analysis, and solution development (Qulub et al., 2023; Yunus & Suryani, 2022). However, learning practices in schools are still often teacher-centered and do not optimally train students' scientific reasoning skills (Kurniawan et al., 2021). As a result, students have difficulty compiling laboratory reports logically and drawing conclusions based on data (Yani et al., 2021). Based on the results of the needs analysis that has been conducted, around 90% of students stated that they needed teaching aids to help them understand water pollution material and wanted practical-based learning to make it more interesting and meaningful. This shows the need for learning media that allows students to conduct real investigations into water quality.

One technology that is relevant to support these activities is Arduino. Arduino is an open-source microcontroller that can be integrated with various sensors, including pH sensors, allowing students to measure water quality directly (Zhaki et al., 2023). In this study, the pH parameter was chosen as the main indicator because it is a basic parameter that shows the acidity or alkalinity of water through hydrogen ion concentration. From a physics perspective, pH sensors work based on electrochemical principles involving electrical potential differences due to variations in ion concentration in solutions. This makes the use of pH sensors relevant to electrical and measurement systems in physics learning. Previous studies have shown that the use of Arduino in science education can increase student engagement in the processes of measurement, data analysis, and hypothesis testing (Çoban, 2020). However, most studies still focus on the technical aspects of device use or general cognitive learning outcomes. Research that specifically integrates Arduino-based water quality measuring devices with the Problem-Based Learning model to train students' scientific reasoning indicators in the context of water pollution investigation is still limited. In addition, there has not been much research that designs teaching aids that function as investigative instruments that allow students to formulate hypotheses, collect empirical data, analyze measurement results, and draw evidence-based conclusions.

According to García-Tudela, (2023), Arduino also encourages teachers to be more creative and innovative in designing challenging and meaningful learning activities for students. With the help of this technology, teachers are no longer stuck with lecture-style or conventional learning methods, but can create activities that involve direct exploration, problem solving, and real-world application of concepts. This can certainly improve students' scientific reasoning skills and make the learning process more lively and contextual, as students are faced with situations that require scientific thinking and practical skills. In addition, teachers are also encouraged to continue learning and innovating so that science learning becomes more interesting and in line with the times. The use of Arduino encourages teachers to design more creative and innovative learning, so that they no longer rely on conventional methods. Through exploration and problem-solving activities, students are actively involved in scientific processes such as observation, data analysis, and drawing conclusions. Learning becomes more contextual because students are faced with real-world problems that require the application of scientific reasoning skills. Thus, the use of Arduino plays an important role in improving students' scientific reasoning skills.

Although various studies have examined the use of Arduino in science education and demonstrated its potential in improving scientific thinking skills, most of these studies still focus on the technical aspects of using the device or on improving cognitive learning outcomes alone (Çoban, 2020; Kusuma et al., 2021). Research that specifically integrates Arduino-based water quality measurement tools with problem-based learning models to develop scientific reasoning skills in the context of water pollution investigation is still limited. Furthermore, there are not many studies that have designed teaching aids that not only function as demonstration media, but also as investigative instruments that enable students to actively formulate hypotheses, collect field data, analyze measurement results, and draw conclusions based on empirical evidence. Unlike previous research that tends to separate sensor development from learning models, this study integrates an Arduino-based water quality measuring tool directly into Problem-Based Learning (PBL) syntax to empirically stimulate specific indicators of students' scientific reasoning.

Therefore, this study aims to develop an Arduino-based pH measuring tool integrated with the Problem-Based Learning model to improve high school students' scientific reasoning skills on water pollution material. The novelty of this research lies in the systematic integration of microcontroller technology and pH sensors with investigation-based learning design in the PBL model. This research not only contributes to the development of technology-based learning media but also to the strengthening of scientific reasoning skills as an important competency in science education.

2. METHOD

This study used the Research and Development (R&D) method with the ADDIE model (Analysis, Design, Development, Implementation, and Evaluation). The research was conducted in a limited trial phase, which focused on product development and initial effectiveness testing before conducting a large-scale operational trial (Dwitiyanti et al., 2020).

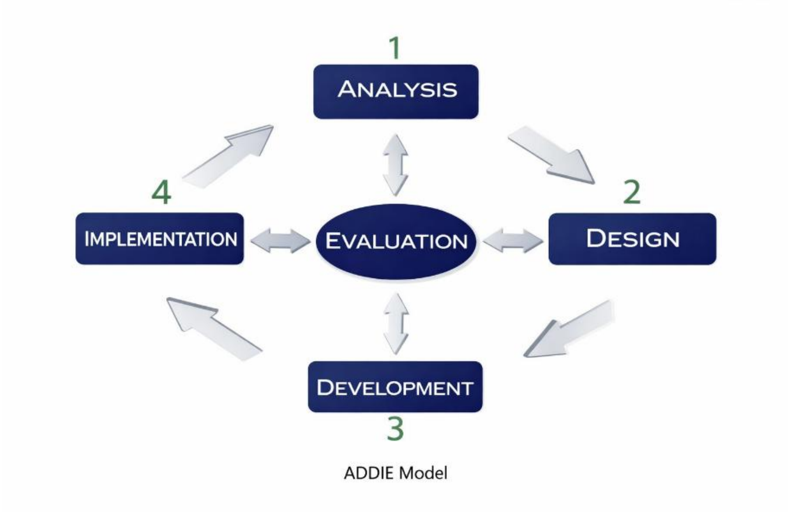

Figure 1 ADDIE Research Stages

The research subjects were 28 students in class X-8 and one physics teacher at SMA Negeri 7 Kota Bengkulu in the even semester of the 2025/2026 academic year. In the Analysis stage, a needs analysis was conducted through literature studies and the distribution of questionnaires to students to identify learning problems in water pollution material and the low level of students' scientific reasoning skills.

In the Design stage, an Arduino-based water quality measuring device was designed, integrated with a pH sensor, a Problem-Based Learning (PBL) teaching tool, and a scientific reasoning test instrument. During the Development stage, the device was assembled and programmed using Arduino IDE, then validated by two physics education lecturers and one high school physics teacher. Revisions were made based on the validators' suggestions before implementation in the classroom. During the Implementation stage, learning was carried out using the Problem-Based Learning (PBL) model assisted by an Arduino-based water quality measuring device. The learning steps included: (1) orientation on water pollution issues, (2) organizing students into investigation groups, (3) conducting experiments using Arduino-based pH measuring devices, (4) data analysis and hypothesis testing, and

(5) presentation of results and conclusion drawing. The learning was conducted over three meetings. To test the effectiveness of the product, this study used a pre-experimental design with a one-group pretest-posttest format. Scientific reasoning tests were administered before and after the learning process. In the evaluation stage, the data were analyzed using feasibility percentages, N-Gain analysis to determine the improvement in abilities, and descriptive analysis of student responses.

The main instrument in this study was an Arduino-based water quality measurement device consisting of a pH sensor, Arduino Uno microcontroller, LCD, and power source, where the pH sensor detected the acidity level of the water, the data was processed by Arduino Uno, and the measurement results were displayed on the LCD. The hardware design was presented in the form of a block diagram as shown in Figure 2.

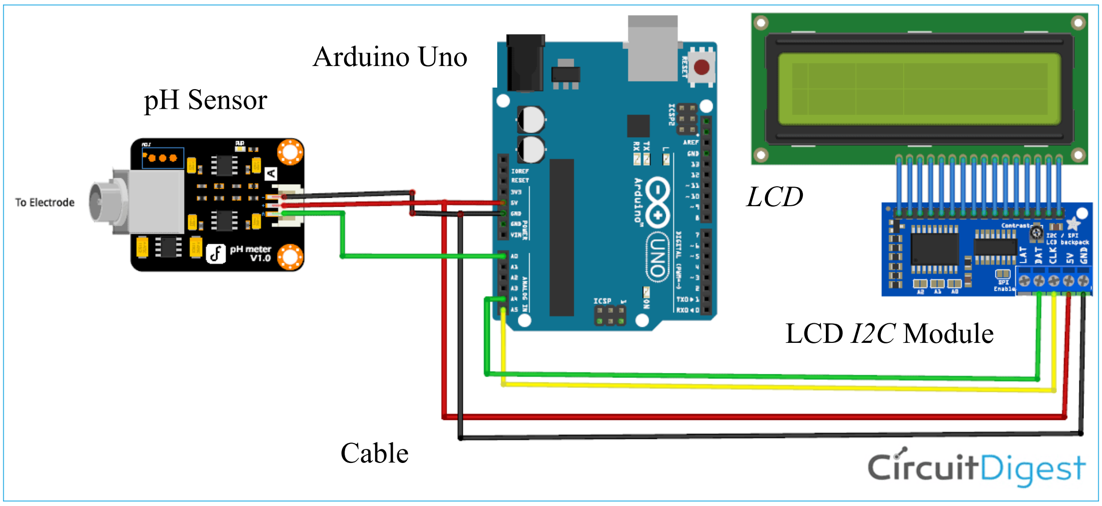

Figure 2 Hardware Design

Feasibility Analysis of Teaching Aids

The feasibility of water quality measurement tools in this study was assessed using an expert validation questionnaire given to two physics education lecturers and one high school physics teacher. The validation instrument covered aspects of content suitability with water pollution material, accuracy of tool design and function, clarity of display and information, safety of use, and tool integration with learning objectives. Each aspect was assessed using a rating scale, and the scores obtained were calculated to determine the level of suitability. The validation data were analyzed by calculating the suitability percentage using Equation (1), which is the ratio between the total score obtained and the maximum ideal score multiplied by 100%. This percentage was then used as the basis for determining the suitability category of the teaching aids according to the established criteria (Pahlevi, 2019).

$$\text{Validation of the Eligibility of Teaching Aids} = \frac{Total\ Score}{Maximum\ Ideal\ Total\ Score} \times 100\% \quad \text{.........} \quad (1)$$

The determination of media suitability is carried out using percentage values as a reference in data assessment. The criteria for the suitability percentage of learning media are presented in Table 1. (Pahlevi, 2019).

Table 1. Feasibility Percentage

Score Range	Category
81,26% - 100%	Very Eligible
62,51% - 81,25%	Quite Eligible
43,76% - 62,5%	Less Eligible
25% - 43,75%	Not Eligible

Analysis of Scientific Reasoning Skills Improvement

The measurement of students' scientific reasoning in this study used an instrument adapted from Lawson's Classroom Test of Scientific Reasoning (LCTSR), which is a standard test that has been widely used to measure students' scientific reasoning abilities at various levels of education. The aspects of scientific reasoning measured in this study included deductive hypothesis reasoning, conservation reasoning, proportional reasoning, and probabilistic reasoning. The instrument used has been adapted to the learning context and characteristics of high school students through a process of language adaptation and editorial adjustments without changing the original constructs being measured. To ensure content validity, the adapted instrument was reviewed by two physics education experts and one learning evaluation expert, and the assessment results showed that the instrument was valid and suitable for use. The pretest and posttest scores obtained were then calculated and analyzed using the Normalized Gain (N-Gain) formula as shown in Equation (2). The N-Gain calculation results were then interpreted based on improvement categories to determine the level of effectiveness of using teaching aids in improving students' scientific reasoning (Lolita et al., 2025).

$$\text{N-Gain} = \frac{Posttest\ Score - Pretest\ Score}{Ideal\ Maximum\ Score - PreTest\ Score} \quad .... \quad (2)$$

The analysis of improvements in students' scientific reasoning was conducted based on the N-Gain index classification in accordance with the criteria in Table 2.

Table 1. N-Gain Index Category

N-gain Score	Category
$g > 0,7$	High
$0,4 \leq g \leq 0,7$	Moderate
$g \leq 0,4$	Low

Questionnaire Response Analysis

In this study, student response questionnaires were used to obtain an overview of student responses to the use of water quality measurement teaching aids. Student response data is an important indicator in assessing the advantages and limitations of teaching aids. Student response data analysis was conducted by calculating the response percentage based on the scores obtained, as formulated in Equation (3) (Eka et al., 2025).

$$\%\ \text{Respon} = \frac{Total\ Score}{aximum\ Ideal\ Total\ Score} \times 100\% \quad (3)$$

The classification of student response percentages refers to the criteria listed in Table 3.

Table 2. Percentage of Questionnaire Responses

Score Range	Category
81,26% - 100%	Very Good
62,51% - 81,25%	Fairly Good
43,76% - 62,5%	Not Very Good
25% - 43,75%	Not Good

This study focused on the development and limited testing of water quality measurement teaching aids in improving students' scientific reasoning skills through water pollution investigation. The research subjects were limited to one class, namely 10th grade students at a public high school in Bengkulu City. The measurements in this study only covered the improvement of students' scientific reasoning skills on the subject of environmental pollution. In addition, the evaluation of the teaching aids was conducted within a limited period of time, so it was not yet able to represent the impact of using teaching aids on learning in the long term.

3. RESULTS AND DISCUSSION

RESULTS

This study is research on the development of an Arduino-based water quality measurement tool with a pH sensor for environmental pollution material to improve the scientific reasoning skills of 10th grade high school students. The development process was carried out through five main stages, namely analysis, design, development, implementation, and evaluation.

Analysis Stages

The analysis stage aims to collect and review various information as a basis for developing water quality measurement teaching aids used to improve high school students' scientific reasoning through water pollution investigation. At this stage, learning problems are identified and information relevant to the characteristics of the product to be developed is collected. A needs analysis was conducted to identify fundamental problems in the physics learning process, particularly in the subject of water pollution. A review of previous studies showed that learning was still dominated by theoretical material delivery, making it difficult for students to understand the concepts concretely. Therefore, water quality measurement teaching aids were needed as a learning medium that could help students develop scientific reasoning skills. In addition to literature studies, a needs analysis was also conducted on students through a questionnaire covering the learning context, preferences for teaching aids, and the suitability of the media with the applicable curriculum.

Based on the results of the needs analysis, the specifications for the hardware and software used in the development of the teaching aid were determined. The hardware includes an Arduino Uno as the main microcontroller, an analog pH sensor for measuring water quality, a 16×2 alphanumeric LCD with an I2C module as a display medium, and connecting cables. Meanwhile, the software used in this study is Arduino IDE, which functions for programming and controlling the teaching aid system.

Design Stages

The second stage of this research was the design stage. Software design was carried out using Arduino IDE (C/C++) because this platform is open-source, easy to use, and compatible with various sensors, including the pH sensor used in this study. The pH sensor was chosen because it is capable of accurately detecting water acidity levels and is relevant to the water pollution material studied by students. The Arduino Uno microcontroller was used as the data processing center because it has a simple, stable interface and is suitable for STEM-based learning at the high school level. The program developed included the process of reading sensor data, calculating pH values, processing data, and displaying measurement results via an I2C LCD screen (16×2), which was chosen because it is pin-efficient and facilitates device integration. Additionally, pH data is also displayed through the Serial Monitor as a means of documenting and evaluating the experiment results. The selection of these components considers aspects of ease of use, affordability, and relevance in supporting students' scientific investigation and reasoning development activities. See Figure 3 for the pH sensor testing flowchart with Arduino.

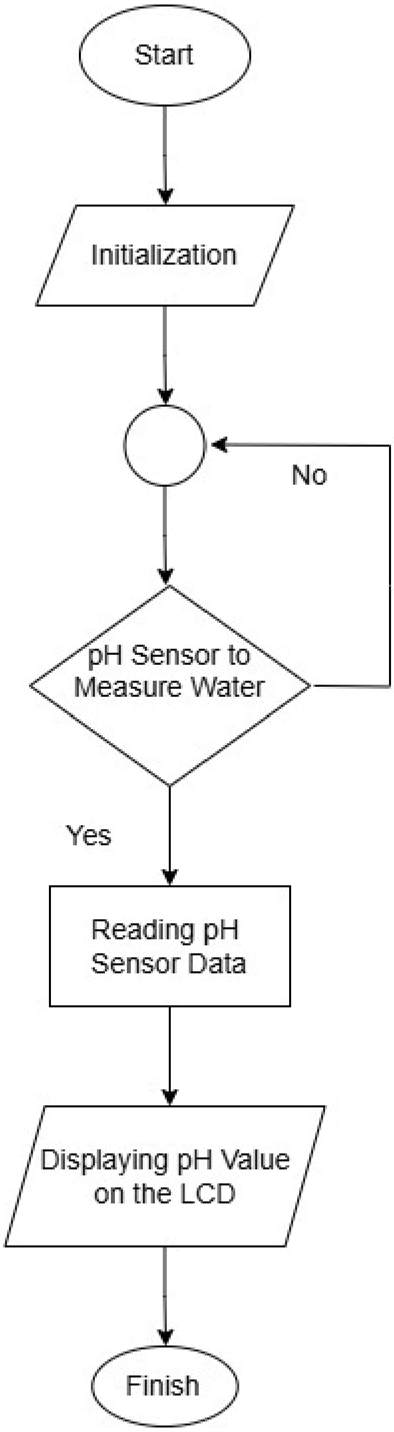

Figure 3. Flowchart for Testing a pH Sensor with Arduino

Development Stages

After the design stage, the next phase was the development stage, in which a water quality measurement device was constructed. The device was developed using an Arduino Uno microcontroller connected to a pH sensor via jumper cables. The pH sensor was equipped with a probe to measure the acidity or alkalinity of water. An LCD display was then connected to the Arduino board to enable real-time visualization of measurement results. Finally, the entire circuit was enclosed in a protective casing, and the appropriate program code was uploaded to the microcontroller. Once assembled and programmed, the Arduino-based system could be operated effectively. Students were able to observe the measured pH values directly through the LCD display and the serial monitor on a laptop connected to the Arduino.

Prior to its implementation in classroom learning, the device underwent a limited trial phase to evaluate its accuracy and suitability. The trial involved comparing pH measurement results obtained from the developed device with those obtained using pH litmus paper. The samples tested included acidic solutions, alkaline solutions, and solutions with extreme acidity and alkalinity levels. The results indicated that the classification of solution properties obtained from the device was consistent with those determined using litmus paper. However, while litmus paper only provides qualitative information (acidic or basic), the developed device is capable of displaying quantitative pH values. These numerical results can be observed directly through the LCD display and serial monitor, thereby offering more precise and data-driven measurement information. This finding aligns with previous research by Karangan et al (2019), which reported that pH sensor–based measuring devices can serve as an effective alternative to manual measurement methods using litmus paper, particularly due to their ability to provide quantitative data.

Table 3. Expert Validation Results

No	Validator	Feasibility Percentage	Category
1.	Validator 1	100	Very Worthy
2.	Validator 2	92,71	Very Worthy
3.	Validator 3	96,88	Very Worthy
	Average	**96,53**	Very Worthy

Table 4 shows that the validation results from the validators state that the teaching aids developed are feasible in accordance with Table 4 using equation (1). The validators' assessment shows that the teaching aids meet the feasibility criteria in terms of tool efficiency, tool durability, aesthetics, technical components, safety, and suitability with learning materials, so that they can be applied in learning. The expert validation scores for each indicator are listed in Table 5.

Table 4. Percentage of Eligibility for Each Aspect

No	Aspect	Feasibility Percentage	Category
1.	Tool Efficiency	97,22	Very Worthy
2.	Tool Durability	94,05	Very Worthy
3.	Aesthetics	94,05	Very Worthy
4.	Technical Components	97,78	Very Worthy
5.	Safety	95,83	Very Worthy
6.	Compatibility with Materials	100	Very Worthy

Based on Table 5, the validation results show that the Arduino-based teaching aid developed has good quality and meets the standards of feasibility as a physics learning medium. The high percentages in terms of efficiency, durability, aesthetics, technical components, safety, and suitability with the material indicate that the tool was designed systematically and took into account the learning needs in the classroom. This indicates that the tool not only functions technically but is also pedagogically relevant in supporting students' scientific investigation process.

Implementation Stages

Figure 4. Conducting Water Pollution Investigations

The implementation stage of learning begins with administering a pre-test to students to determine their initial scientific reasoning abilities before learning takes place. Next, learning begins with problem orientation, where researchers present contextual problems related to water pollution in the students' environment through provocative questions and real phenomena. In the student organization stage, students are divided into groups to discuss the problem, formulate questions, and develop initial hypotheses.

In the investigation stage, students conduct investigative activities as shown in Figure 4, where they use water quality measurement tools to collect data on water quality parameters. All learning activities are guided by Student Worksheets (LKPD) designed to train the scientific reasoning process, including the ability to observe, analyze data, and draw conclusions. Furthermore, in the development and presentation stage, students compile and present the results of their investigations.

The final stage of learning is the analysis and evaluation of the problem-solving process, in which students and researchers reflect on the results and learning process. After the entire learning series is complete, students are given a posttest to determine the improvement in their scientific reasoning skills after the application of the Problem-Based Learning (PBL) model assisted by water quality measurement tools. All learning activities were carried out over three lessons.

Based on the analysis of the pretest and posttest data, students' scientific reasoning skills showed improvement after the implementation of learning using the developed teaching aids. The average pretest score of 36.46 indicated that the students' initial scientific reasoning skills were still in the low category, particularly in understanding the relationship between concepts and physical phenomena in water pollution material. After the learning was carried out, the average posttest score increased to 89.47, which showed a significant increase in students' scientific reasoning skills..

This improvement is reinforced by an N-Gain value of 0.83, which is in the high category, indicating that the learning applied is effective in developing students' scientific reasoning skills. These results show that the use of the Problem-Based Learning (PBL) model supported by Arduino-based teaching aids can encourage students to observe phenomena, propose hypotheses, analyze data, and draw conclusions based on empirical evidence. This process is a key indicator of scientific reasoning.

The findings of this study are in line with research conducted by Sapitri et al (2023), which states that the use of Arduino-based teaching aids in physics learning can improve students' scientific thinking skills through direct involvement in the observation and measurement process. Table 6 presents the scores for the improvement in students' scientific reasoning skills based on the indicators of scientific skill abilities.

Table 5. N-Gain Results per Scientific Reasoning Ability Indicator

No Question	Scientific reasoning skill indicators	*Pre-test Score*	*Postest Score*	*N-Gain*	Category
1-2	Deductive hypothesis	47,22	95,83	0,92	High

No Question	Scientific reasoning skill indicators	*Pre-test Score*	*Postest Score*	*N-Gain*	Category
3-4	Conservation	32,41	91,2	0,86	High
5-6	Proportional	32,87	85,65	0,78	High
7-8	Probabilistic	33,33	85,19	0,77	High

Table 6 presents the N-Gain results per indicator of students' scientific reasoning ability, obtained from a comparison of pretest and posttest scores after implementing learning using Arduino-based water quality measurement tools through the Problem Based Learning (PBL) model. N-Gain is used to determine the level of improvement in students' scientific reasoning ability on each indicator more objectively.

Student response is one of the important indicators in assessing the success of the learning process. Low response can hinder the effectiveness of learning, while positive response indicates the level of comfort and acceptance of students towards the learning media used. Student interest in learning media contributes to increased focus and engagement during the learning process, thereby minimizing boredom (Purnama et al., 2025). To measure these responses, a student response questionnaire was used that covered three aspects, namely material presentation, scientific reasoning ability, and usefulness, as presented in Table 7.

Table 6. Student Responses to Teaching Aids

Aspect	Percentage (%)	Category
Presentation	98,61	Very Good
Scientific reasoning skills	98,15	Very Good
Usefulness	99,07	Very Good
Average	**98,61**	**Very Good**

Based on Table 7, which was calculated using equation (3), the results of the student response questionnaire showed that the environmentally-based water quality measurement teaching aids received a rating of very good in all aspects assessed. In terms of presentation, the teaching aids were considered capable of presenting water pollution material in a coherent and contextual manner, making it easier for students to understand the procedures for observing and measuring water quality in environmental investigation activities.

Evaluation Stage

The evaluation stage in this study was conducted through formative and summative evaluations to ensure that the water quality measurement teaching aids developed were truly feasible and effective for use in learning. Formative evaluations were carried out at each stage of the ADDIE model, starting from analysis, design, development, to implementation. During the development stage, the teaching aids were validated by two physics education lecturers and one high school teacher, with an average suitability percentage of 96.53% in the highly suitable category. All aspects of the assessment, such as the efficiency of the tools, durability, aesthetics, technical components, safety, and material suitability, showed excellent results.

Meanwhile, the summative evaluation conducted after the entire learning process showed that the use of Arduino-based teaching aids combined with the Problem-Based Learning (PBL) model was effective in improving students' scientific reasoning skills as a whole. This was demonstrated by an increase in all scientific reasoning indicators in the high category, namely hypothetical deductive (0.92), conservation (0.86), proportional (0.78), and probabilistic (0.77), as well as an overall N-Gain value of 0.83. This effectiveness was also reinforced by the students' response to the use of teaching aids, which obtained an average of 98.61% in the excellent category, so that the tools were declared suitable for learning needs and easy to useThus, it can be concluded that the teaching aids developed are very feasible in terms of design, and effective in helping students analyze measurement data and draw evidence-based conclusions on water pollution.

This study has several limitations. The implementation was carried out on a limited sample in one school, so the generalization of the research results is still limited. In addition, the high positive response from students may have been influenced by the novelty effect, as the use of Arduino-based teaching aids was a new experience for students. The presence of new technology in the classroom can temporarily increase motivation and engagement, which has the potential to affect learning outcomes. Therefore, further research with a larger sample and a longer implementation period is needed to test the consistency and long-term effectiveness of improving students' scientific reasoning.

DISCUSSION

Discussion On The Feasibility Of Water Quality Measurement Tools

The learning media in the form of teaching aids is considered feasible because it is able to carry out its learning functions in accordance with the objectives set. In terms of efficiency and technical components, the use of Arduino microcontrollers allows pH measurements to be carried out accurately and in real time, so that students can immediately observe changes in data and perform analysis. This advantage supports experiment-based learning and scientific reasoning. In addition, the sturdy construction and reusability of the tool make it practical and economical for long-term learning. These findings are in line with the research by Masyruhan et al. (2020), which states that Arduino-based teaching aids have a good level of accuracy and meet the criteria for learning media suitability.

From a safety perspective, the tool has been designed with safety in mind for use in school environments, thereby minimizing risks to students. In terms of material suitability, the teaching aid helps visualize the abstract concept of water pollution in a more concrete way through direct measurement data. Thus, the high validation results not only reflect the technical quality of the device, but also show that it is effective in supporting student engagement and the development of scientific reasoning in physics learning.

Discussion On Improving Students' Scientific Reasoning Ability

Based on Table 6, all scientific reasoning indicators showed improvement in the high category, with the hypothetical-deductive indicator demonstrating the largest increase (N-Gain = 0.92). This substantial gain indicates that students experienced significant development in their ability to formulate hypotheses, test assumptions using empirical data, and draw logical conclusions based on evidence. The particularly high increase in hypothetical-deductive reasoning can be explained by the specific learning mechanism facilitated by the Arduino-based pH measurement device within the Problem-Based Learning (PBL) framework.

In the learning process, students were first confronted with contextual problems related to water quality and were required to predict the pH level of different samples. These predictions functioned as explicit hypotheses. Students then tested their hypotheses using the Arduino-connected pH sensor, which provided real-time quantitative data displayed on the LCD screen and serial monitor. The availability of precise numerical results enabled students to directly compare predicted and observed values. When discrepancies occurred, students were encouraged to reconsider their assumptions and revise their explanations. This structured sequence hypothesis formulation, empirical testing, data observation, comparison, and conclusion mirrors the core structure of hypothetical-deductive reasoning. Unlike conventional litmus paper methods, which provide only qualitative classifications (acidic or basic), the Arduino-based device presents measurable numerical data that demands deeper analytical processing and logical inference. Therefore, the technology does not merely serve as a measuring tool but actively triggers evidence-based reasoning cycles.

This mechanism is consistent with Lawson’s Scientific Reasoning Framework, which emphasizes the coordination of hypothesis generation, control of variables, evaluation of empirical evidence, and logical deduction. The Arduino-supported investigation creates an environment in which students systematically engage in these reasoning processes. Immediate data feedback strengthens the connection between prediction and evidence, thereby reinforcing deductive thinking patterns.

In addition, the conservation (N-Gain = 0.86), proportional (N-Gain = 0.78), and probabilistic (N-Gain = 0.77) indicators also improved in the high category. The increase in conservation reasoning indicates that students were able to recognize the consistency of water acidity despite differences in representation or measurement format. Improvement in proportional reasoning reflects enhanced ability to interpret numerical relationships among pH values, which inherently require understanding logarithmic and comparative quantitative structures. Meanwhile, gains in probabilistic reasoning suggest that students became more capable of considering data variability, potential measurement uncertainty, and alternative interpretations of water quality conditions.

From the perspective of Piaget's theory of cognitive development, these improvements particularly in conservation and proportional reasoning are characteristic of formal operational thinking. The integration of Arduino-based measurement activities within a PBL context likely facilitated students' transition toward more advanced cognitive structures by engaging them in systematic experimentation, quantitative analysis, and reflective evaluation of evidence. Overall, the combination of Arduino-based teaching aids and inquiry-oriented learning did not merely enhance conceptual understanding but functioned as a structured cognitive scaffold that strengthened students' scientific reasoning at multiple levels.

The combination of direct measurement activities, data analysis, and scientific discussion makes learning more meaningful and contextual, thereby positively impacting the improvement of students' scientific reasoning skills. These findings are consistent with the results of research by Vanz dan Blancia (2025), which shows that the application of problem-based learning can significantly improve students' scientific reasoning skills. This improvement occurs because students are actively involved in the process of investigation, data analysis, and drawing conclusions based on real phenomena, thereby encouraging the development of high scientific reasoning skills.

Discussion Of Students' Responses To Teaching Aids

Based on Table 7, the results of the questionnaire show that the Arduino-based water quality measuring tool received a very positive response from students with an average percentage of 98.61% in the Very Good category. All aspects assessed, namely presentation (98.61%), scientific reasoning skills (98.15%), and usefulness (99.07%), were in the very good category. The high score in the presentation aspect shows that the teaching aids are able to present water pollution material clearly, systematically, and contextually. An LCD display that displays pH data directly helps students understand the measurement results in a concrete way. The presentation of this real-time data makes learning no longer abstract, but based on real phenomena that can be observed directly by students. In the aspect of scientific reasoning skills, the percentage of 98.15% shows that students feel an increase in their scientific thinking process during learning. This indicates that the use of props not only serves as a demonstration medium, but actually encourages students to make observations, analyze data, interpret results, and draw conclusions based on empirical evidence. This positive response strengthens the quantitative findings on the N-Gain results which are in the high category. Meanwhile, the usefulness aspect obtained the highest score (99.07%). This shows that students consider teaching aids to be helpful in understanding the concept of water pollution as well as being relevant to their surrounding environmental conditions. Learning that is associated with real problems increases the perception of meaningful learning, so that students feel that the investigative activities carried out have direct benefits in daily life. Overall, the very high response of students shows that the products developed meet the practicality and acceptability aspects in R&D research. This positive response is an important indicator that the integration of Arduino technology with PBL models is able to create interactive, contextual, and student-centered learning.

In terms of scientific reasoning skills, the teaching aids were rated as excellent because they encouraged students to make direct observations, collect data, and analyze the relationship between measurement results and water pollution levels. Through simple environment-based experiments, students were actively involved in the scientific process, from formulating problems and interpreting data to drawing conclusions based on empirical evidence. This shows that the use of water quality measurement teaching aids is effective in supporting the development of students' scientific reasoning.

Furthermore, in terms of usefulness, teaching aids received excellent ratings because they helped students understand the concept of water pollution in a concrete and practical way. Students were able to relate the results of the experiments to the conditions of their surrounding environment, making learning more meaningful and relevant to their daily lives. This finding is in line with the research by Izwan et al. (2024), which states that the use of environment-based teaching aids received a very good response from students because they were able to increase engagement, interest in learning, and scientific activities during the learning process.

4. CONCLUSION

This study successfully developed an Arduino-based water quality measurement teaching aid and pH sensor that is feasible and effective for use as a physics learning medium to improve high school students' scientific reasoning skills through water pollution investigation. Expert validation results show that the teaching aid is in the highly feasible category in terms of efficiency, durability, aesthetics, technical components, safety, and material suitability. The implementation of Problem-Based Learning (PBL) supported by this teaching aid has been proven to significantly improve students' scientific reasoning skills, as indicated by an increase in N-Gain scores in the high category for all scientific reasoning indicators, including hypothetical-deductive, conservation, proportional, and probabilistic reasoning. In addition, students' responses to the use of teaching aids showed a very good category in terms of presentation, scientific reasoning ability, and usefulness, indicating that teaching aids are capable of creating contextual, interactive, and meaningful learning. Thus, the water quality measurement teaching aids developed play an important role as innovative and effective learning media in training students' scientific reasoning skills and fostering awareness of environmental issues, particularly water pollution.

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