



The Effectiveness of Using an Arduino Uno Microcontroller-Based Radioactivity Detector as a Physics Learning Medium to Improve Students' Scientific Literacy

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DOI: <http://dx.doi.org/10.18592/tarbiyah.v15i1.18370>

Key Words:

arduino uno
effectiveness
radioactivity detector
scientific literacy

Received : 14-10-2025

Revised : 20-06-2026

Accepted : 22-06-2026

Published : 24-06-2026

Abstract:

This study aims to analyze the effectiveness of using an Arduino Uno-based radioactive detector as a physics learning medium to improve students' scientific literacy. The study employed a quasi-experimental method with a one-group pretest-posttest design, involving 30 students from the Physics Education Study Program, Faculty of Mathematics, Science, and Technology, Universitas PGRI Pontianak. The research instrument was a scientific literacy test consisting of five main indicators: explaining scientific phenomena, designing scientific inquiry, interpreting data and evidence, applying scientific concepts, and demonstrating scientific attitudes. Data were analyzed using the N-Gain score to measure improvement and a paired sample t-test to determine the significance of the difference between pretest and posttest results. The findings revealed an average N-Gain score of 0.366, categorized as moderate, indicating a noticeable improvement in students' scientific literacy after learning with the Arduino Uno-based detector. The t-test results showed $t = 14.97$ and $p = 0,356 \times 10^{-15}$ (< 0.05), suggesting a statistically significant difference between pretest and posttest scores. These results demonstrate that the use of the Arduino Uno-based radioactive detector is effective in enhancing students' scientific literacy, particularly in explaining scientific phenomena and interpreting experimental data.

To cite this article: Boisandi, Nurussaniah, Matsun. (2026). The Effectiveness of Using an Arduino Uno Microcontroller-Based Radioactivity Detector as a Physics Learning Medium to Improve Students' Scientific Literacy . *Tarbiyah: Jurnal Ilmiah Kependidikan*. 15(1), 41-55.

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Introduction

The development of science and technology (IPTEK) in the 21st century demands that education adapt to rapid change. Students in higher education, particularly those in science and physics education, are not only required to master theory but also to possess critical and creative thinking skills, as well as the ability to connect scientific concepts to real life. One of the key competencies students must possess is scientific literacy (Sari & Hidayat, 2021; Retdwina Rusma et al., 2025). Scientific literacy does not only mean understanding scientific concepts, but also the ability to use this knowledge to make decisions, solve problems, and adopt a scientific attitude towards the phenomena around us (Chen & Zhou, 2022).

According to the Organisation for Economic Co-operation and Development (PISA) report, scientific literacy encompasses three important aspects: (1) understanding scientific phenomena, (2) evaluating and interpreting scientific evidence, and (3) using scientific knowledge to address real-world problems. This means that scientific literacy requires high-level thinking skills and analytical skills that cannot be developed solely through theoretical learning in the classroom (Halim & Fatimah, 2020). However, the reality on the ground shows that physics learning in higher education is still dominated by conventional methods such as lectures, assignments, and simple lab work that tend to be results-oriented, rather than process-oriented. This results in students having less opportunity to experience scientific processes directly, such as observing, measuring, analyzing data, and drawing conclusions based on evidence. As a result, students' scientific literacy levels remain relatively low, particularly in terms of conceptual understanding and application of knowledge in new situations (Rahman & Nurhayati, 2022).

One physics topic with significant potential for developing scientific literacy is radioactivity. This topic relates to real-life natural phenomena, such as the decay of atomic nuclei, radiation detection, and its applications in health, industry, and the environment. Unfortunately, learning about radioactivity is often presented theoretically without practical application. This is due to the limited availability of radiation detection equipment in educational laboratories, the high cost of commercial devices, and safety and regulatory issues regarding the use of radioactive sources. As a result, students struggle to fully grasp the concept of radiation due to a lack of empirical experience in conducting measurements or simple experiments. To address these limitations, innovative learning media are needed that are safe, affordable, and capable of providing meaningful learning experiences.

One solution currently being widely developed is the use of the Arduino Uno microcontroller in science learning (Matsun et al., 2023). Arduino is an open-source microcontroller board that is easy to program and compatible with a variety of sensors, including radiation sensors such as Geiger-Müller tubes (GM tubes). By integrating Arduino and a Geiger tube, a simple radioactive detector can be created that can detect radiation from natural sources in the environment, such as potatoes, carrots, or objects containing natural isotopes.

The compatibility between the science literacy instrument and the data generated by the Arduino sensor is very important so that the tool is not only used as a demonstration medium, but can also support the assessment of students' science literacy skills. Good science literacy instruments generally measure three main aspects,

namely scientific knowledge, science process skills, and scientific attitudes. This is in line with *the Scientific Inquiry Literacy Instrument (SILI)* which is able to measure scientific inquiry knowledge and skills simultaneously (Darman et al., 2024). Data generated by Arduino sensors in real-time, such as the number of radiation counts per minute from a Geiger-Müller tube, can be empirical evidence that students use to practice their ability to analyze, evaluate, and interpret data. These skills are an important part of science literacy according to the PISA framework (OECD, 2023).

Technological developments also show that the assessment of inquiry skills increasingly utilizes digital devices and real measuring tools because they are considered more capable of describing students' scientific thinking processes than ordinary written tests (Jiang et al., 2025; Toma, 2024). In addition, various studies have shown that low-cost Arduino-based sensors are capable of producing data that is of close quality to standard research devices, so the measurement results are valid enough to be used in evidence-based learning activities (Ga & Chang, 2025). The integration of *physical computing* and *the Internet of Things (IoT)* in science learning also allows students to be directly involved in the process of data collection, processing, and interpretation, which is an essential component of various modern science literacy instruments (Seo et al., 2024).

In radioactivity materials, the use of Arduino-based Geiger-Müller detectors has been proven to function not only as a radiation detection tool, but also as a means of learning that encourages students to design measurement procedures, collect data, and scientifically analyze radiation sources (Arcani et al., 2024). These findings are strengthened by the results of a metaanalysis showing that the use of digital devices in physics experiments has a positive impact on improving students' scientific thinking skills compared to conventional experimental methods (Jiang et al., 2025). In addition, the development of multidimensional science literacy instruments emphasizes that the empirical evidence used in learning must be in accordance with the competencies to be measured so that the results of the assessment truly reflect students' ability to use and interpret scientific evidence (Mede et al., 2026; Osborne & Allchin, 2024). Thus, the data generated by Arduino-based radioactive detectors have characteristics that are in harmony with the various dimensions measured in science literacy instruments. This conformity is an important foundation for research because it not only assesses the performance of the tool from the technical side, but also examines its contribution in measuring and developing students' science literacy more authentically.

Using an Arduino Uno-based radioactive detector as a learning tool offers several advantages. First, this tool provides students with hands-on experience in measuring radiation, analyzing data, and understanding the relationship between theory and experimental results. Second, this tool is safe to use, as it does not require a high-intensity radioactive source. Third, from a pedagogical perspective, this tool encourages students to think scientifically and develop scientific literacy, as the learning process involves observation, analysis, and interpretation of data (Matsun, Boisandi, Sari, Hadiati, & Saputri, 2021).

Several studies have shown that microcontroller-based media can improve the quality of science learning. Research by Pusch et al., (2021) found that the integration of Arduino in science learning was able to improve students' analytical thinking skills and scientific literacy through project-based experimental activities. La et al. (2021)

developed an Arduino-based radiation measurement device for physics education and demonstrated very positive results, particularly in improving students' experimental skills, [Matsun et al. \(2021\)](#) reported that the use of Arduino-based physics learning media can improve students' higher order thinking skills and understanding of physics concepts.

However, the literature review reveals that most research integrating Arduino into learning focuses on topics such as electricity, magnetism, and temperature sensors. However, the use of Arduino as a learning medium for radioactivity is still very limited, especially at the university level in Indonesia. This topic is highly relevant to everyday life and holds significant potential for developing students' scientific skills. Furthermore, research specifically assessing the effectiveness of Arduino-based media in improving scientific literacy is still rare ([Daniels et al., 2025](#)).

This situation creates a research gap that needs to be bridged. Studies are needed that not only focus on tool development but also measure its pedagogical impact, particularly on improving students' scientific literacy. Through an experimental approach, the effectiveness of using an Arduino Uno-based radioactive detector can be quantitatively tested, for example by comparing the scientific literacy skills of students learning using this tool with those learning conventionally.

Furthermore, this research also possesses novelty in several aspects. First, it integrates technical verification of a radiation detection device with pedagogical evaluation of student learning outcomes, resulting in a comprehensive approach between technology and education. Second, the developed device is innovative and economical, capable of being produced independently by educational institutions without relying on expensive commercial equipment. Third, the results of this study can serve as a model for implementing technology-based learning in higher education, relevant to the Independent Learning and Independent Campus (MBKM) policy, where students are encouraged to be active, creative, and capable of independent exploration.

Thus, research on the effectiveness of using an Arduino Uno microcontroller-based radioactive detector as a physics learning medium is expected to make a significant contribution to the development of science learning innovation in Indonesia. Through the use of this tool, students not only understand the concept of radiation conceptually but also develop scientific skills such as observing, reasoning, and making decisions based on evidence from scientific literacy itself.

In addition to benefiting students, this research is also expected to provide practical contributions to lecturers and higher education institutions, providing an effective, safe, and affordable alternative to experimental learning media. The results can also serve as a basis for developing a technology-based curriculum in physics education, thereby creating a generation of educators who are not only conceptually competent but also adaptable to technological advances.

In other words, this study aims to answer the main question: Is the use of an Arduino Uno microcontroller-based radioactive detector effective in improving students' scientific literacy in physics learning? The answer to this question is expected to strengthen the understanding that the integration of simple technologies like Arduino can bridge theory and practice in science education, while simultaneously fostering a scientific culture among students.

Research Method

This study uses a quantitative approach with a quasi-experimental method. This approach was chosen because the study aims to measure the effectiveness of using learning media in the form of a radioactive detector based on the Arduino Uno microcontroller on improving students' scientific literacy. The design used in this study is the One Group Pretest–Posttest Design, which is a design that involves one experimental group that is given treatment using innovative learning media, where student learning outcomes are measured before and after the treatment is given. This design allows researchers to determine differences in students' scientific literacy abilities due to the use of the developed learning media.

The research was conducted in the Physics Education Study Program, Faculty of Mathematics and Natural Sciences, Universitas PGRI Pontianak in the even semester of the 2025/2026 academic year. The study population was all fourth-semester students who had taken the Core Physics course. The sample selection was carried out by purposive sampling, because only students who had studied the concept of radioactivity could participate in learning activities using Arduino Uno-based media. The sample used in this study was 30 students.

The research instruments consisted of a science literacy test, student activity observation sheets, and learning tools to support the experimental process. The science literacy test used was based on the PISA (Programme for International Student Assessment) science literacy framework, which includes four indicators: the ability to explain scientific phenomena, evaluate and design scientific investigations, interpret scientific data and evidence, and apply scientific concepts in real life ([Ásványi & Gedeon, 2025](#)). The science literacy test is in the form of a reasoned multiple-choice test with 20 questions, which have been validated by three experts in the field of physics education and learning instruments to ensure content validity and language clarity.

This research procedure consists of three stages, namely preparation, implementation, and data analysis. In the preparation stage, the researcher developed and tested an Arduino Uno-based radioactive detector consisting of a Geiger-Müller sensor component, an Arduino Uno microcontroller, and an LCD screen to display radiation data in real-time. In addition, learning tools such as Semester Learning Plans (RPS), student worksheets (LKM), and assessment instruments were also prepared. The implementation stage was carried out through four meetings. In the first meeting, students were given a pretest to determine their initial scientific literacy skills. The next meeting was used for learning activities using the Arduino Uno-based radioactive detector media, where students conducted observations, experiments, and discussions based on the results of radiation detection from various sources. After all learning activities were completed, students were given a posttest to measure improvements in scientific literacy skills.

The research data were analyzed using the N-Gain test to determine the improvement in students' scientific literacy skills after treatment. The formula used refers to Hake (1998). The N-Gain value was then categorized into three levels: high ($g > 0.70$), medium ($0.30 \leq g \leq 0.70$), and low ($g < 0.30$). Learning media is considered effective if the average N-Gain value is in the medium or high category ([Net et al., 2024](#)).

In addition to the N-Gain calculation, normality and homogeneity tests were also conducted to ensure the data met the requirements for parametric analysis. A paired sample t-test was then used to determine significant differences between students' pretest and posttest scores. The results of this statistical test were used to quantitatively confirm the effectiveness of the learning media.

The research success criteria were determined based on three aspects, namely (1) the average N-Gain value ≥ 0.30 , (2) there was a significant difference between the pretest and posttest scores ($p < 0.05$), and (3) the level of student involvement in learning reached a minimum of 75% based on the activity observation sheet (Annisa et al., 2024).

Results and Discussion

This study aims to determine the effectiveness of using a Radioactive Detector based on the Arduino Uno Microcontroller as a physics learning medium in improving students' scientific literacy. Data were obtained through pretests and posttests on 30 students of the Physics Education Study Program at PGRI Pontianak University. The instruments used include scientific literacy indicators including: (1) Explaining scientific phenomena, (2) Designing and evaluating scientific investigations, (3) Interpreting scientific data and evidence, and (4) Attitudes towards science.

The analysis results show a significant increase in students' scientific literacy scores after participating in learning using Arduino Uno-based media. Statistical data can be seen in Table 1. The average pretest score of 53.18 increased to 70.05 in the posttest. Based on the N-Gain calculation, an average of 0.366 was obtained, which is included in the moderate category. This means that learning with Arduino Uno-based radioactive detector media provides a significant increase in students' scientific literacy, although it has not yet reached the high category.

The paired sample t-test showed a t value of 14.97 with $p = 3.56 \times 10^{-15}$ (<0.05). This value indicates a significant difference between the pretest and posttest scores. Thus, it can be concluded that the use of Arduino Uno-based learning media is effective in improving students' scientific literacy.

In addition to the statistical test, an effect size calculation was also performed using Cohen's d formula, and the results showed a value of 2.73 (Hedges' $g \approx 2.68$). This value falls into the very large effect category, meaning that the learning intervention had a strong impact on students' scientific literacy skills. In other words, the use of microcontroller-based radioactive detector media not only resulted in statistically significant improvements but also had a significant practical impact on the learning process.

Tabel 1. Statistik Parameter

No	Statistical Parameter	Value	Description
1	Number of Respondents (n)	30	Physics Education Students
2	Average Pretest Score	53.18	Initial scientific literacy score
3	Average Posttest Score	70.05	Scientific literacy after treatment
4	Average N-Gain	0.366	Moderate category (Hake)
5	t-value	14.97	Paired sample t-test result
6	p-value	3.56×10^{-15}	< 0.05 , significant
7	Cohen's d	2.73	Very large effect size
8	Hedges' g	2.68	Very large effect size (adjusted for small sample size)

Further analysis was conducted to assess student improvement in each scientific literacy indicator. The results showed that all indicators improved after the learning process, as seen in Figure 1. The scientific phenomena indicator increased from an average of 53.13 to 70.07. This improvement indicates that students were able to better understand and explain scientific concepts after conducting direct observations using a radioactive detector. Real-life experiment-based learning helped students connect theory with phenomena in their environment. The Designing Scientific Investigations indicator score increased from 48.47 to 65.20. This improvement indicates that students are becoming skilled at designing experiments, determining variables, and selecting the right tools and materials for radioactivity measurements. Active involvement in the use of the Arduino Uno microcontroller also trains systematic thinking and problem-solving skills. The Interpreting Data and Scientific Evidence indicator increased from 51.23 to 69.25. This indicates that students have become more skilled at reading, processing, and analyzing measurement data. Through data display on an OLED screen and recording to an SD card, students can interpret experimental results in a more structured manner. Attitude towards Science Indicator The highest increase occurred in this indicator, namely from 59.23 to 76.70. This increase reflects that students demonstrate greater curiosity, critical thinking, and have a scientific attitude in understanding issues related to radiation and environmental safety.

The performance of the science literacy measurement instrument used in this study showed good results when paired with empirical data generated by Arduino Uno-based radioactive detectors. This can be seen from the consistency of improvement in all science literacy indicators, from the explanation of scientific phenomena to attitudes towards science, which indicates that the instrument is able to capture changes in student competence sensitively to the type of learning experience based on real measurements given. This is in line with the principle of developing contemporary science literacy instruments, which emphasize that a good instrument must be able to measure students' competence in evaluating and using empirical evidence directly, not just declarative knowledge (Mede et al., 2026).

Compared to previous research that generally developed science literacy instruments based on written scenarios or simulations without the involvement of physical measuring instruments, this study showed a fundamental difference because students interacted directly with real sensor data (radiation count in CPM and $\mu\text{Sv}/\text{hour}$ conversion), so that the process of interpreting the data measured by the science literacy instrument was really based on authentic empirical evidence. not hypothetical data. This kind of contextualized assessment approach has been shown to increase the accuracy of measuring science literacy competencies compared to conventional instruments, as students are faced with real-world measurement situations that demand authentic scientific reasoning (Matsun et al., 2026).

In addition, when compared to studies that measured inquiry skills in high school students through conventional written tests, the results of this study showed a greater improvement in the indicators of designing and evaluating scientific investigations, which confirmed that direct involvement in designing measurement procedures using sensory tools contributed more significantly to the mastery of inquiry skills than mere theoretical exposure (Čipková et al., 2025). In terms of tool

development, the improvement in the results of science literacy measurement in this study is also supported by the quality of the data generated by the sensors; previous research has shown that Arduino-based low-cost sensor devices, if designed and calibrated appropriately, are capable of producing data equivalent to *research-grade* measurement instruments), so that the validity of the data used by students to practice the interpretation of scientific evidence can be accounted for technically (Roy et al., 2025). This is important because without the reliability of the data from the hardware side, the increase in scores on science literacy instruments risks only reflecting the administrative skills of using the tools, not the actual science literacy competencies.

These findings also reinforce the results of research showing that the integration of *physical computing* into school science inquiry allows students to experience the full cycle of data collection, processing, and interpretation independently, which is the conceptual basis for improved achievement in data interpretation indicators and scientific evidence in this study (Ga & Chang, 2025). Thus, the observed increase in science literacy is not only the result of exposure to new technologies, but a reflection of the compatibility between the characteristics of the data generated by the Arduino sensor and the dimensions measured by the science literacy instrument, which is the main differentiator of this study from previous studies that tend to test the effectiveness of science literacy tools and instruments separately.

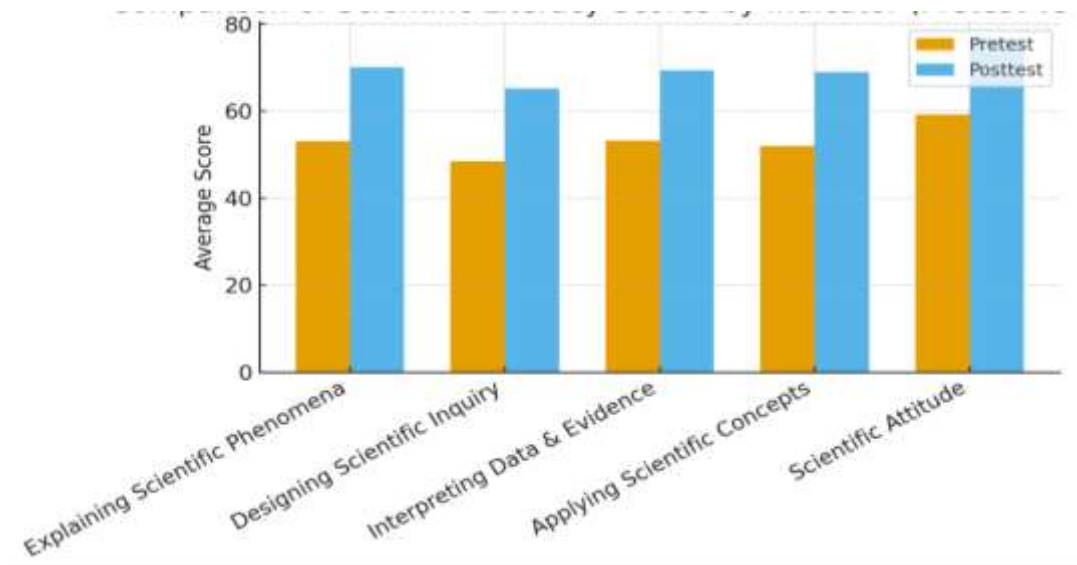


Figure 1. Comparison of Scientific Literacy by Indicator

The results of this study indicate that Arduino Uno-based learning media is effective in improving students' scientific literacy. This is in line with research (Hadiati et al., 2024) who found that integrating microcontroller technology into science learning can improve students' analytical thinking and problem-solving skills. This technology-based learning enables students to learn actively through exploration, experimentation, and reflection on the results obtained. According to Straight & Materials (2021), The use of Arduino-based tools enhances the learning experience by providing students with the opportunity to directly visualize experimental data. This increases motivation and engagement in the learning process, ultimately positively impacting learning outcomes (Rahmawati et al., 2025).

In the context of physics learning, a microcontroller-based radioactive detector helps students understand the concept of radiation, which is usually abstract (Veeramanickam et al., 2022). By directly observing the changes in the number of pulses from a Geiger-Muller tube, students can connect the theory of radioactivity with real-world measurements. This process strengthens the connection between theory and practice, improving their ability to explain scientific phenomena and interpret scientific evidence logically (Matsun, Boisandi, Sari, Hadiati, & Hakim, 2021).

The results of the study showed that measurements of radioactivity levels in two types of natural food ingredients, namely carrots and potatoes, produced values of $0.11 \mu\text{Sv/hr}$ and $0.13 \mu\text{Sv/hr}$. These values are within safe limits according to international standards (IAEA, 2020), which state that natural exposure levels in the environment range from $0.05\text{--}0.20 \mu\text{Sv/hr}$. These results indicate that both food ingredients have normal levels of natural radioactivity and are not harmful to human health. However, the small difference between the two values is interesting to study in the context of learning scientific literacy, because it opens up space for students to interpret data scientifically, trace natural radiation sources, and understand the relationship between food ingredients and the geophysical environment in which they grow. The results of the observations can be seen in Figure 2.



Figure 2. Observation Results: (a) Carrot $0.11 \mu\text{Sv/hr}$, (b) Potato $0.13 \mu\text{Sv/hr}$

This radioactivity measurement activity was conducted using an Arduino-based Geiger Muller Counter (GMC) detector, designed to be simple yet accurate for learning purposes. The use of this microcontroller-based tool not only allows students to perform direct measurements but also fosters an understanding of how radiation detectors work and the basic concepts of radioactivity. According to Khairati et al. (2021), Integrating digital technology like Arduino into physics learning can improve technological literacy while strengthening scientific literacy because students interact directly with measuring instruments and the data they produce. In this context, students become not just users of technology but also small researchers who design, measure, and interpret the results of their experiments (García-Llamas et al., 2025). The implementation of the observation can be seen in Figure 3.

Conceptually, this activity develops three main aspects of scientific literacy, namely the ability to explain phenomena scientifically, evaluate scientific investigations, and interpret scientific data and evidence (Dewantara et al., 2024). First, in terms of explaining the phenomenon scientifically, students were able to understand that radioactivity is a natural phenomenon resulting from the decay of atomic nuclei, such as uranium, thorium, or potassium-40, which are found in the soil and absorbed by plants. They explained the differences in measurement results between carrots and potatoes by relating them to their mineral content and different growing locations. This understanding demonstrated the students' ability to connect empirical data with scientific concepts. This is in line with the findings Wang et al. (2024) The ability to explain phenomena scientifically develops better when students gain direct experimental experience rather than just studying theory in class.

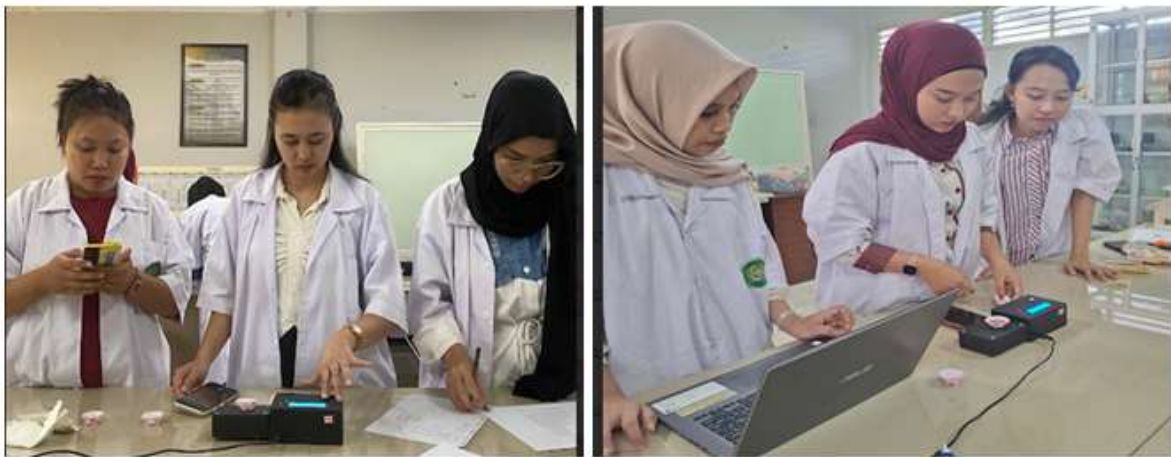


Figure 3. Observation Implementation

Second, the indicator for evaluating and designing scientific investigations is reflected in how students conduct measurements, determine the 20-second observation time, and carefully record data. Students also discuss possible sources of error, such as electromagnetic interference, sensor position, and laboratory environmental conditions. This process demonstrates an understanding of the scientific method and the importance of variable control in experiments. Apriliya Yolanda et al. (2024) emphasizes that the skill of evaluating scientific investigations is an integral part of the formation of students' scientific mindset, especially in the field of experimental physics.

Third, in terms of interpreting data and scientific evidence, students used measurement data to conclude that the difference in radioactivity between potatoes and carrots was within the range of natural variation. They also compared their observations with literature showing that foods grown in soil with high mineral content, such as potatoes, tend to have slightly higher radiation exposure than vegetables grown on the surface, such as carrots. This process demonstrated the ability to analyze and interpret evidence-based data. L. Wang & Chen (2020), Activities that involve direct analysis of experimental data can improve understanding of scientific concepts and evidence-based thinking skills.

In addition to improving scientific literacy skills, this activity also trains students in critical and collaborative thinking. Observations in Figure 3 show students working in groups, discussing, recording results, and using laptops to process data. This collaborative process is important because scientific literacy encompasses not only cognitive aspects but also socio-communicative ones, namely the ability to clearly communicate scientific results and arguments to others (Harbers et al., 2024). Students learn how to interpret measurement results collectively, compare views, and prepare reports that meet scientific standards (Hidayati et al., 2024).

This integration of experimental activities, collaboration, and digital technology supports the Science Literacy Technology Society (SLiTS) learning principles which emphasize the relationship between science, technology, and society (Haatainen & Aksela, 2021). By measuring natural radioactivity in food materials, students not only understand physics concepts, but also become aware of social and environmental issues relevant to everyday life, such as food safety and exposure to natural radiation Megawati, (2024) explains that learning based on socioscientific issues can foster students' reflective awareness of the application of science in society.

Furthermore, the use of Arduino-based tools fosters scientific curiosity and innovation among students (Casaburo, 2021). They can modify sensors, set observation times, and display results in digital graphs (Wasilah et al., 2024). This is in line with the view Görgülü Ari & Meço, (2021) Microcontroller-based learning provides authentic experiences in the modern scientific workplace that relies on digital data-driven analysis. Furthermore, students learn to understand that the radioactivity data obtained is very small compared to the hazard threshold, thus fostering a scientific understanding of radiation risks and safety in everyday life.

Conclusion

Based on the results and discussion, it can be concluded that the use of an Arduino Uno-based Radioactive Detector as a physics learning medium is effective in improving students' scientific literacy. The average N-Gain value of 0.366, categorized as moderate, indicates that students experienced a meaningful improvement in conceptual understanding and scientific reasoning after participating in learning activities using this medium.

Furthermore, the results of the paired t-test ($t = 14.97$; $p = 3.56 \times 10^{-15} < 0.05$) confirm that there is a statistically significant difference between students' pretest and posttest scores. This demonstrates that the Arduino Uno-based learning media has a substantial impact on improving scientific literacy, particularly in the indicators of explaining scientific phenomena and interpreting experimental data.

Therefore, this study concludes that the integration of microcontroller technology into physics learning serves as an innovative and effective approach to address the challenges students face in understanding abstract concepts such as radioactivity. The use of the Arduino Uno-based detector not only enriches students' learning experiences through experiment-based activities but also fosters critical thinking and scientific attitudes aligned with 21st-century education competencies.

Acknowledgements

Thank you to Universitas PGRI Pontianak, through the Institute for Research and Community Service (LPPM), for providing funding for this research.

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