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Project-Based Learning (PjBL) in Electronics Course : An Arduino-Based Automatic Watering Prototype

Yustina Yesisanita Yeyen✉**, Maria Yunita**

Department of Physics Education, Faculty of Teacher Training and Education,
Universitas Nusa Nipa, Indonesia

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Abstract

The Electronics course necessitates the integration of theoretical knowledge, practical skills, and scientific communication competencies. Technology-based Project-Based Learning (PjBL) provides an effective means to address these requirements by engaging students in meaningful, hands-on projects. This study examines the implementation of Arduino-based PjBL through the development of an automatic watering prototype and evaluates its impact on students' scientific communication skills in the Electronics course. A qualitative research design was adopted, with participants comprising students enrolled in the course. Data collection methods included classroom observations, project documentation, and student reflections. Scientific communication skills were assessed using six indicators: clarity of delivery, appropriate use of scientific terminology, structure and logic of presentation, data interpretation, responses to questions, and written communication. The results demonstrated that students presented their projects more systematically, beginning with problem identification, followed by system design, testing results, and conclusions. Students were able to explain circuit errors and propose corrective actions logically. Additionally, written reports became more structured and were substantiated by measurement data. Overall, the findings suggest that Arduino-based PjBL effectively supports the development of students' scientific communication skills in Electronics education.

✉ correspondence:
Jl. Kesehatan No.3, Beru, Kec. Alok Tim., Kabupaten Sikka, Nusa Tenggara Timur. 86094, Indonesia
E-mail: yeyensanita010@gmail.com

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INTRODUCTION

Technological developments in the Industrial Revolution 4.0 and Society 5.0 era demand transformations in higher education learning systems. The use of technology in education is urgently needed, especially to help increase student motivation and facilitate teachers in delivering lessons (Yesisanita Yeyen, 2025). Higher education is expected to produce graduates who not only master theoretical knowledge but also possess practical skills and problem-solving abilities relevant to industry needs (Otermans et al., 2025). In this context, learning electronics requires an approach that integrates theoretical concepts with meaningful practical applications. Project-Based Learning (PjBL) has been proven to be an effective pedagogical approach in improving the quality of learning in higher education (Bhagwat & Kulkarni, 2025; Novalia et al., 2025) and has resulted in significant improvements in student learning outcomes across affective, cognitive, and behavioral domains (Sánchez-garcía & Reyes-de-cózar, 2025).

In the field of Electronics and STEAM Education, PjBL is widely used to promote deeper conceptual understanding through experimentation and project design (Filipe & Baptista, 2024). This approach enables students to apply theoretical knowledge in a practical context. Particularly for Physics education students, the project-based approach has been shown to be effective in improving problem-solving skills and preparing students for the workplace demands (Wang et al., 2025).

Arduino is widely used in electronics and programming education due to its simplicity, flexibility, and affordability (García-tudela & Duo-terr, 2024; Tselegkaridis & Sapounidis, 2024). It supports applications ranging from basic projects to complex systems such as robotics and smart devices through extensive open-source libraries (Nireekshana et al., 2025; Ogunbiyi et al., 2025). In the Indonesian educational context, the application of Arduino has shown positive results in improving students' conceptual understanding, practical skills, and confidence in experimentation (Asri et al., 2024; Erwinsyah et al., 2025).

An Arduino-based automatic plant watering system represents a relevant electronics learning project that integrates sensors, actuators, microcontroller programming, and automatic control while addressing real-world challenges including water conservation and sustainable agriculture. The system enables students to design devices that monitor soil moisture in real time and automatically control water pumps based on plant needs (Badar et al., 2025; Olayaki-luqman et al., 2025; Prakosa et al., 2024).

Project-Based Learning (PjBL) integrated with Arduino has been widely reported to increase student engagement, technical skills, and problem-solving abilities in science and STEM learning (Dat, 2025; Nannim et al., 2025). However, most previous studies emphasize technical outcomes and general learning achievements, while students' scientific communication skills receive limited research attention (Oh, 2025). Unlike previous studies (Taufik, 2025) which positioned scientific communication as a supporting activity or secondary learning outcome, this study specifically analyzed scientific skills as core competencies observed through scientific communication indicators during the learning process. Using a descriptive qualitative approach, this study examines the development of students' scientific communication skills through Arduino-based PjBL and offers pedagogical insights for small classes with limited resources.

METHODS

This study adopted a descriptive qualitative approach (Listyani et al., 2024) to explore the implementation of the Project-Based Learning (PjBL) model and its contribution to enhancing students' scientific communication skills in Electronics courses. This approach was chosen because it enables researchers to obtain a comprehensive understanding of learning processes, classroom interactions, and students' learning experiences within authentic educational contexts (Shofia et al., 2023).

The research was conducted in the Electronics course offered to students of the

Physics Education Study Program at Nusa Nipa University. The research subjects consisted of nine third-semester students who were directly involved in Project-Based Learning (PjBL) activities, including the design and development of Arduino-based automatic prototypes. Participants were selected using purposive sampling based on predefined criteria aligned with the research objectives (Dahal et al., 2019). The limited number of participants was consistent with the descriptive qualitative approach, which emphasized in-depth analysis of the learning process and students' scientific communication skills.

Data were collected through observation, documentation, and student reflection. Observations were made during the project implementation process and presentation activities. The observation instrument consisted of structured observation sheets containing indicators of scientific communication skills, including: a) clarity of scientific presentation, b) appropriate use of scientific terms, c) ability to explain project procedures and results, d) data interpretation, e) ability to respond questions and participate in discussions, and f) written communication. Student reflections were collected through reflective writing that documented students' experiences in communicating their projects, challenges encountered during the process, and their perceptions of the role of Arduino-based PjBL in developing scientific communication skills. In addition, documentation in the form of student project reports, design sketches, and prototype photographs was collected to support and verify findings from observations and reflections. To facilitate observation and assessment, students' scientific communication skills were evaluated using the indicators presented in Table 1.

The learning process followed the PjBL model, encompassing stages of problem identification, project planning, prototype creation, system testing, presentation, and project publication, as illustrated in Figure 1.

Table 1. Indicators for Assessing Scientific Communication Skills

Number	Observed Aspect	Scientific communication skill indicators
1.	Clarity of delivery	Explaining concepts and work processes in a logical, clear, and understandable manner
2.	The use of appropriate scientific terminology	Using electronic terms, symbols, and concepts accurately and appropriately
3.	Structure and logic	Organizing explanations and project presentations in a coherent, systematic, and logical sequence
4.	Interpretation of data	Accurately interpreting test results and project data
5.	Response to questions	Responding to questions with relevant and scientifically-grounded explanations
6.	Written communication	Presenting project reports using a scientific structure and clear, academic language.

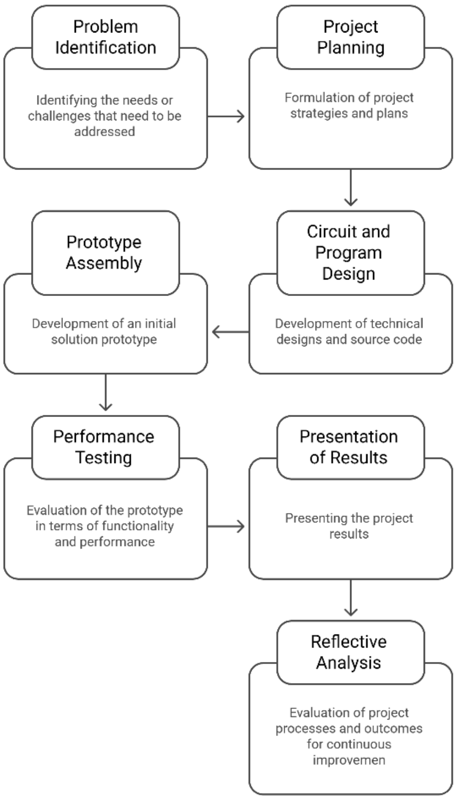

Figure 1. Flowchart of the Application of the Project-Based Learning (PjBL) Model in Electronics Courses

Figure 1 presents a flowchart illustrating the application of the PjBL model in the Electronics course through the development of Arduino-based automatic prototypes. This diagram illustrates the stages including problem identification, project planning, design and programming planning, prototype assembly, functional testing, and presentation and reflection of results. This diagram provides a systematic learning overview and research procedures implemented in this study. To further clarify the relationships among system components, a block diagram of the Arduino-based automatic watering system is presented in Figure 2.

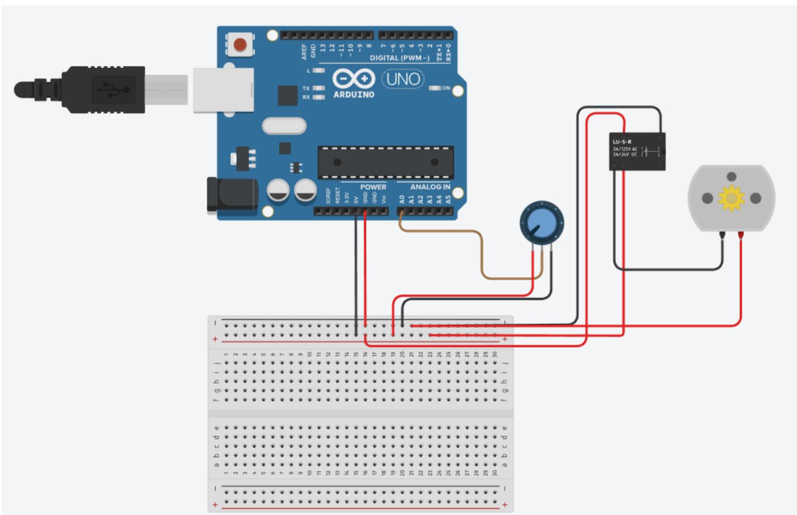

Figure 2. Schematic Diagram of Arduino-Based Automatic Irrigation System

Figure 2 presents a block diagram illustrating the workflow of the Arduino-based automatic irrigation system. The soil moisture sensor detects the water content in the growing medium and transmits the data to the Arduino microcontroller, which functions as the system's control unit (Aisyah et al., 2025). The data are processed to determine the watering conditions, after which the Arduino sends a control signal to the relay module, which functions as an electronic switch (Saharin et al., 2024). The relay subsequently activates or deactivates the water pump, enabling automatic irrigation based on plant requirements.

The data analysis followed the stages of data reduction, data presentation, and conclusion drawing. Observation notes, project documentation, and student reflections were analyzed by organizing the data according to predetermined scientific communication skill indicators. Each indicator was analyzed descriptively to identify changes and developments in students' scientific communication skills throughout the implementation of Project-Based Learning. Data validity was ensured through source and technique triangulation by comparing data obtained from observations, student reflections, and project documentation to ensure consistency (Fikri et al., 2025). The analysis results were also discussed with colleagues to minimize potential misinterpretations.

RESULTS AND DISCUSSION

In this research, the Project-Based Learning (PjBL) model was applied in the Electronics course, in which students were tasked with developing an Arduino-based automatic plant watering system. The implementation of PjBL followed several stages: (1) formulating essential questions, (2) designing the project, (3) developing a project schedule, (4) executing and monitoring the project, (5) testing the project outcomes, and (6) conducting evaluation and reflection. The participants consisted of nine Physics Education students enrolled in the Electronics course. Students were required to design, assemble, and test the automatic watering system using soil moisture sensors, Arduino microcontrollers, relay modules, and mini water pumps. Throughout the learning process, the lecturer acted as a facilitator by providing both technical and conceptual support. The application of PjBL led to the successful development of an automatic watering prototype that operated as intended. The system monitored soil moisture levels using a sensor, and when the moisture dropped below a predetermined threshold, the Arduino activated the relay to switch on the water pump and initiate automatic irrigation. These results are in line with previous findings reported by Mehta et al. (2025).

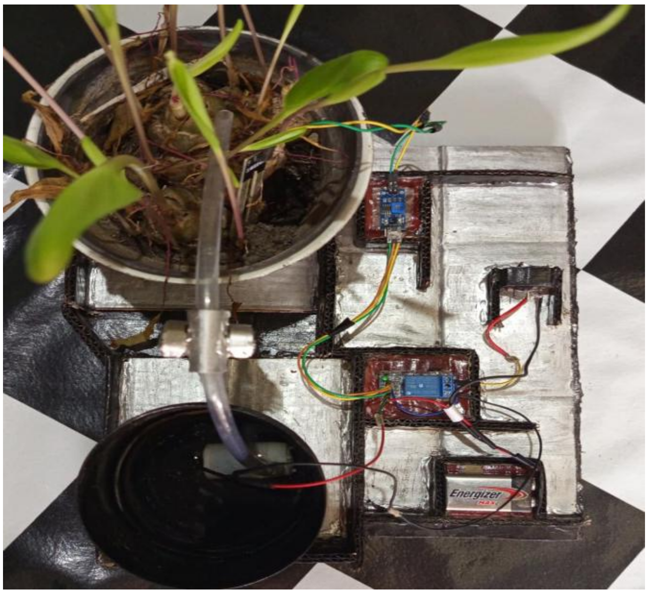

Figure 3. Arduino-based Automatic Watering Prototype

Figure 3 shows a prototype of the Arduino-based automatic irrigation system developed by students through the application of the PjBL model. This prototype consists of an Arduino R3 microcontroller as the control center, a soil moisture sensor as input, a relay module connecting the control system to the actuator, and a mini water pump as the irrigation device. All components were assembled on a prototype board and connected using jumper cables. The system was designed to operate automatically, activating the water pump when the sensor detected soil moisture levels below the programmed threshold. This prototype represents students' learning outcomes in integrating electronics concepts, programming skills, and project-based problem-solving abilities. These results consistently support the achievement of concepts, learning motivation, and teamwork skills relevant to current educational demands (Yan et al., 2025).

The application of the PjBL model not only resulted in functional prototype products but also contributed to the development of students' scientific communication skills, as indicated in Table 1. In terms of clarity of delivery, students were able to explain the system concepts and operational workflow coherently, beginning with the sensor as input, followed by data processing on the Arduino, and concluding with the water pump as output. Compared to the beginning of the course, these explanations were delivered using clearer and more structured language. In terms of the use of appropriate scientific terminology, students began to get used to using electronic terms and concepts such as soil moisture sensors, relays, microcontrollers, and threshold values in context. This finding indicates that students not only understood the operational principles of the device but were also able to articulate its functions using appropriate scientific terminology.

In terms of structure and logic, students presented their ideas and arguments in a more systematic manner. During presentations, students structured their explanations sequentially, beginning with the problem background, followed by system design, test results, and conclusions. When errors occurred in the circuit or program, students were able to explain the causes of the problems and propose corrective measures in a logical manner. In terms of data interpretation, students were able to interpret sensor test results and system performance in a simple but accurate manner. Several groups presented soil moisture data in tabular form and explained the differences between dry and wet soil conditions and their effects on water pump performance. In terms of responding to questions, students could answer questions from lecturers and peers based on experimental evidence from experiments rather than mere speculation. In terms of written communication, students' project reports were structured more systematically, consisting of introduction, objectives, methods, results, and conclusions. The language used in the reports was clearer and more precise. These findings indicate that students' scientific communication skills developed not only in oral presentations but also in written reports.

The observation results showed that students were actively involved throughout the learning process. Group discussions were intense, especially during the prototype design and testing stages. Students showed high enthusiasm for projects that were contextual and closely related to real-world problems.

Table 2. Student Activity Observation Results

Activity Aspects	Categories	Description
Active Discussion	High	Students actively asked questions and expressed their opinions
Teamwork	Good	There was a clear division of tasks among group members.
Independent Learning	High	Students independently searched for learning resources and references.
Responsibility	Good	The project was completed according to the specified schedule

These findings may be understood within the framework of constructivist and experiential learning theories. Students constructed their own understanding through activities like designing, testing, and improving the systems they created (Tsai et al., 2023; Zhang et al., 2022). The process of making mistakes and correcting them encouraged students to reflect on their work and re-articulate their ideas using coherent and scientific language. Thus, the improvement of scientific communication skills emerges as an integral part of an active and meaningful learning process.

The application of the Project-Based Learning (PjBL) model also contributed to the development of 21st-century skills, including critical thinking, creativity, collaboration, and communication. Students were required to analyze problems, design solutions, and communicate project results through presentations and reports (Yuniwati & Sitepu, 2025). These findings indicate that PjBL is an effective approach for improving the quality of electronics learning while simultaneously enhancing students' scientific communication skills.

CONCLUSION

This study provides evidence that the application of the Project-Based Learning (PjBL) model through the development of an Arduino-based automatic watering prototype effectively integrated students' conceptual understanding, practical skills, and scientific communication skills in the Electronics course. Through activities such as designing and testing the prototype, students not only learned about sensors, circuits, and programming, but also developed the ability to explain their work using clear and scientific language. The findings imply that technology-based project learning is an effective strategy in physics and science teacher education for linking theoretical knowledge with real-world practice while fostering scientific communication skills. However, this study was limited by a relatively small number of participants. Therefore, further research employing mixed-methods designs and larger sample sizes is recommended to obtain a more comprehensive understanding of the effects of Arduino-based PjBL on students' scientific communication skills.

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