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Contextual Practice at SMKN 1 Kasongan, Central Kalimantan: Project-Based Learning for Arduino and IoT (Internet of Things) Based Water Pollution Mitigation

Rendi Indiwara
SMKN 1 Kasongan, Central Kalimantan, Indonesia
email: rendiindiwara3@gmail.com

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Abstract

This article describes the Project-Based Learning (PjBL) practice implemented at SMKN 1 Kasongan, Central Kalimantan, in the context of mitigating river water pollution caused by community activities and illegal mining. Using the PjBL approach, students created and used a water quality monitoring device that works with an ESP8266 microcontroller, TDS and temperature sensors, and an IoT application made with Blynk and AppSheet. This study used a qualitative descriptive method with data collected through observation, digital documentation, student reflection, and teacher formative assessment. The learning outcomes showed that students were able to develop a tool that functioned well in measuring and transmitting water quality data in real-time. In addition to improving technical skills, this project also strengthened 21st-century skills, namely critical thinking, creativity, collaboration, and communication. The local context raised made the learning more meaningful and built students' ecological awareness. Despite technical challenges and tool limitations, this learning succeeded in creating a solution-oriented, collaborative, and relevant learning ecosystem for the 21st century. This practice can be replicated and developed as an integrative contextual learning model in various educational units.

Kata kunci:
Arduino, IoT, Project-Based Learning, Water Pollution

Introduction/ مقدمة

The complexity of global issues and the advancements in digital technology have necessitated that education provide students with 21st-century skills, including critical thinking, communication, collaboration, and creativity, in order to adjust to the changing times. To tackle these challenges, education must be structured to link knowledge with practical application and promote students as proactive, solution-focused learners (Binkley et al., 2014). Project-Based Learning (PjBL) is one educational strategy that is pertinent to these requirements. PjBL promotes student learning through comprehensive investigation of real-world issues, concurrently yielding tangible products as solutions (Bell, 2010). In Indonesia, Project-Based Learning (PjBL) is reinforced by the Independent Curriculum policy, which prioritises the Pancasila Student Profile as the central educational goal, highlighting critical thinking, creativity, independence collaborative spirit, global diversity, and devotion to God Almighty (Kemendikbudristek, 2022)

The incorporation of digital technology into education has become a strategic imperative. Arduino, an open-source microcontroller platform, is extensively utilised in education owing to its versatility, programming simplicity, and endorsement of the STEM (Science, Technology, Engineering, and Mathematics) framework (Banzi & Shiloh, 2015). In conjunction with the Internet of Things (IoT), Arduino enables students to create basic monitoring and automation systems, particularly for environmental concerns like water quality

(Jan et al., 2021). The implementation of IoT in education facilitates real-time data monitoring and context-driven learning based on data (Chuzaini et al., 2022).

The local context is an essential factor in creating significant learning experiences. Katingan Regency, Central Kalimantan, recognised for its abundant water resources, is confronting the issue of river pollution attributed to illicit mining operations and domestic waste disposal. Pebriyanto's research indicates that this pollution elevates total dissolved solids (TDS) and heavy metal concentrations in various river regions, endangering public health and the ecosystem (Pebriyanto et al., 2025).

The combination of a project-based methodology, digital technology, and local context is a strategy that enhances students' technical proficiency while cultivating social and ecological consciousness. This learning practice is deemed effective in enhancing student engagement, cultivating digital literacy, and promoting genuine and significant learning experiences (Dias & Brantley-Dias, 2017; Pearlman & Thomas, 2000).

The purpose of this article is to describe how a vocational high school in Central Kalimantan implemented project-based learning for water pollution mitigation using Arduino and IoT. The emphasis is on documenting the learning process, challenges, project outcomes, and their impact on the development of students' technical competencies and personality.

Method/ منهجية البحث

This research is a qualitative descriptive study designed to document and analyse project-based learning practices related to water pollution mitigation utilising Arduino and the Internet of Things (IoT) (Creswell & Creswell, 2018). The study was conducted in a naturalistic setting, with the author directly involved as a teacher designing, implementing, and evaluating the learning process (Yin & Hollweck, 2015).

This activity took place at SMKN 1 Kasongan, Katingan Regency, Central Kalimantan, during the even semester of the 2024/2025 academic year. The research participants consisted of five tenth-grade TAV students. They engaged in a sequence of educational activities over five weeks, encompassing problem identification, presentation, and reflection on project outcomes.

The course is designed using a Project-Based Learning (PjBL) approach, which allows students to learn by directly participating in real-world projects. The project focusses on the design and implementation of a river water quality monitoring device that incorporates TDS and temperature sensors into a NodeMCU ESP8266 microcontroller (Muhammad Yusri et al., 2024). This device is programmed with the Arduino IDE platform and linked to the Blynk app for online data monitoring. The LCD and the Blynk dashboard display the data generated by the sensors in real-time (Alwansyah & Fahrurozi, 2024).

Data collection was executed via direct observation of student activities, digital documentation (including photographs, screenshots, and project journals), group discussions, and both oral and written reflections from students. Furthermore, teachers conducted formative assessments by observing the collaboration process, evaluating the quality of the created tools, and assessing group presentations.

The collected data was descriptively analysed to determine the effectiveness of learning in terms of technical competency mastery, student engagement, character development, and 21st-century skills like critical thinking, creativity, collaboration, and communication. This analysis also used the Graduate Profile dimensions as the primary evaluation framework. This approach views learning not only as the final project outcome, but also as the process that students go through during the activity.

Result / نتائج البحث

The five-week project-based learning program for water pollution mitigation using Arduino and IoT technology yielded promising results in terms of technical competency acquisition and character development. Understanding the context of local problems was the first step in the learning process, followed by developing solutions, project trials, and presentations. Students actively participated at all stages, demonstrating high motivation and strong collaborative skills.

In the preliminary phase, students exhibited a notable capacity to recognise water pollution problems in their vicinity, especially in the Katingan tributary river. Through the utilisation of news articles, direct observations, and teacher-provided prompts, students successfully identified the fundamental causes of the issue and connected them to the significance of technological solutions. This phase effectively cultivated environmental awareness and a sense of responsibility regarding the issues under investigation.

Image 1. Students Explored the Article about Water Pollution

Notable outcomes commenced upon students' engagement in the design and assembly phase. Students effectively constructed a water quality monitoring apparatus utilising an Arduino R3, ESP8266, TDS, and temperature sensors, featuring an LCD display. The device was subsequently programmed with the Arduino IDE, with the majority of students employing ChatGPT's support to develop and enhance the programming script. This exemplifies a robust amalgamation of technical proficiency and digital literacy.

Image 2. Students assembled NodeMcu and TDS Sensor

The students effectively integrated their system with the Blynk v8 platform, facilitating real-time monitoring of temperature and TDS data via an application. The collected data is visually represented through indicators and graphs accessible via mobile devices. This offers students a tangible comprehension of the Internet of Things (IoT) concept and its application in addressing environmental issues.

Image 3. Students arranged the Iot with Blynk

During the testing phase, students performed restricted trials on three categories of water samples: sewage, river, and bottled drinking water. The measurement results indicated that the device consistently and accurately differentiated the TDS values of various water types: sewer water exhibited the highest TDS, followed by river water, while drinking water had the lowest TDS. The trial effectively established that the devised apparatus possessed sufficient precision and operational capability.

Image 4. Students conducted limited trials with three different waters

The assessment persisted with practical exercises in the Katingan River. Upon securing authorisation from the head of the local neighbourhood association (RT), students conducted measurements at two depths in the river: the riverbed and approximately 30 cm from the surface. The findings indicated that TDS values escalated with depth. This observation indicated that the students not only conducted technical tests on the equipment but also analysed environmental phenomena using the data they collected.

Image 5. Students conducted direct trials in the Katingan River tributary

Each group recorded the project process and outcomes in a digital journal developed with AppSheet, detailing technical challenges, observations, and daily project notes. Upon project completion, students developed an infographic encapsulating their methodology and outcomes, which they subsequently presented to the entire class. All students sequentially

engaged in speaking and responding to enquiries, enhancing their communication abilities and self-assurance.

Image 6. Students did the presentation

Educators implemented formative assessments during the process via observation, discussion, and evaluation of the final outcomes. Assessments highlighted essential 21st-century skills, including critical reasoning (data and problem analysis), creativity (tool and solution design), collaboration (group work), and communication (oral and visual presentations). Student reflections indicated that the majority appreciated the project, experienced a sense of challenge, and expressed a desire to engage in similar projects in the future.

Table 1. Evident Learning Experiences

21st-century skills	**Evident Learning Experiences**
Critical Reasoning	Students dentify instances of river water pollution and potential mitigation strategies. They compare water turbidity across different locations and elevations in the Anak Katingan River. They assess the occurrence of pollution in the river and its implications for usage.
Creativity	Students may explore technological solutions for addressing clean water shortages. They propose locations suitable for measuring TDS.
Collaboration	All students participate in the project through the allocation of tasks. Each student provides input to the contributions of their peers. Each student demonstrates the ability to accept their peers' ideas, which is essential for decision-making regarding the project to be undertaken.
Communication	Students articulated their ideas and opinions during the development of Blynk. Each student presented the results of their project to the class.

Table 2. Student's Learning Outcome

Students	**Score Before Learning**	**Score After Learning**	**Improvement**
A	72	80	8
B	62	70	8
C	22	72	50
D	40	62	22
E	58	82	30

The project effectively delivered a comprehensive learning experience, enabling students to acquire technical competencies while engaging in significant contextual learning, developing empathy for environmental issues, and enhancing character and 21st-century life skills.

Discussion / مناقشتها

The implementation of project-based learning focused on water pollution mitigation through Arduino and the Internet of Things (IoT) demonstrates effectiveness in enhancing students' technical skills, critical thinking, and environmental awareness. The findings support the principles of Project-Based Learning (PjBL), which emphasises the role of students as active participants in the exploration and resolution of real-world issues (Bell, 2010). In this context, students learn about technology and experience its application in addressing environmental challenges within their communities.

The capacity of students to design, program, and test water quality monitoring tools indicates a significant advancement in their technological literacy. This supports the findings of He and Abichandani, indicating that the integration of IoT and microcontrollers in education enhances comprehension of STEM concepts and promotes data-driven learning. Furthermore, student engagement with platforms such as Blynk and AppSheet indicates that digital technology serves as a facilitator for new literacies pertinent to the Industry 4.0 era, rather than a hindrance (He et al., 2017) dan (Abichandani et al., 2022).

This learning effectively promoted the development of students' character in addition to its technical components. The enhancement of graduate profile dimensions, including critical reasoning, creativity, collaboration, and communication, was notably evident during the process. Students effectively communicated ideas, discussed solutions, assigned roles within teams, and presented their work openly. Active participation in all phases of the project indicated a heightened sense of responsibility and environmental awareness. This aligns with Dias & Brantley's assertion that Project-based Learning (PjBL) not only improves content mastery but also fosters critical social and personal competencies (Dias & Brantley-Dias, 2017).

The local context of water pollution in the Katingan River serves as a significant factor in linking educational experiences to the realities faced by students. Learning in familiar environments and addressing relevant issues enhances the significance of education and promotes empathy among students (Mehta & Fine, 2019). This establishes a robust basis for the advancement of ecopedagogy and community-oriented education.

The project implementation faced several challenges. Several students experienced technical challenges while installing the Arduino IDE library and faced constraints with tools and sensors during field measurements. These challenges were integral to the learning process, enhancing problem-solving skills, encouraging initiative in inquiry, and promoting cross-disciplinary collaboration, such as with electronics engineering educators. This illustrates that the learning process in Project-Based Learning (PjBL) is adaptive and promotes lifelong learning.

The facilitator's role is essential from a teacher's perspective. Teachers have transitioned from being the exclusive providers of information to functioning as facilitators of processes, designers of learning experiences, and connectors between theoretical concepts and practical applications. This implementation involves teachers using digital media, including interactive modules and digital journals, to effectively support formative assessment. This approach aligns with the directive of the Ministry of Education, Culture, Research, and Technology concerning holistic, flexible, and student-centered learning (Kemendikbudristek, 2022).

This study illustrates that the integration of the PjBL approach, digital technology, and local issues fosters a more dynamic, significant, and transformative learning environment. This illustrates that vocational schools (SMK) serve not only to impart vocational skills but also to cultivate critical-thinking and environmentally aware learners prepared to address global challenges in a contextual manner.

Conclusion/ الخلاصة

Project-based learning focused on water pollution mitigation through Arduino and the Internet of Things (IoT) has demonstrated a notable enhancement in learning outcomes within vocational schools, particularly in the development of technical competencies and the reinforcement of student character. Contextual activities enable students to recognize real-world problems in their environment, develop technology-based solutions, and present their findings systematically. This project enhances technological skills, including assembly, programming, and IoT system integration, while also reinforcing the aspects of the Graduate Profile: critical reasoning, creativity, collaboration, and communication.

Learning gains significance as it addresses local issues pertinent to students' lives, including river water pollution resulting from community activities and illegal mining. The incorporation of digital media, including interactive modules, the Blynk platform, AppSheet, and the Arduino IDE, enhances the learning experience and advances students' digital literacy essential for the 21st century. The project's success is bolstered by the active participation of teachers as facilitators, the implementation of process-based formative assessments, and the engagement of both the school and local communities in field practice.

This learning encounters challenges, including restricted tools, technical programming issues, and insufficient implementation time. These challenges constitute a fundamental aspect of the learning process, fostering student resilience and independence.

Ultimately, it is anticipated that this best practice can be duplicated and enhanced in other educational institutions, serving not merely as a technical innovation but also as a comprehensive, transformative, and contextual learning paradigm to equip a generation of learners to confront forthcoming environmental and technological challenges.

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