Journal on Smart Learning Technologies

Nahrowi, N., Cahyaningsih, A. A., Sholihah, I., Azizah, M .U., & Rahmandhani, Z. A. (2026). Navigating Digital Learning in the Infrastructure Gap: Adaptive PjBL Strategy in the RPL Department of Vocational High Schools. *Journal on Smart Learning Technologies, 2* (2), 46-56.

DOI: https://doi.org/10.26740/jslt.v2i2.53522

The online version of this article can be found at our journal page:
https://journal.unesa.ac.id/index.php/jslt/issue/view/2003

Published by:
Educational Technology Department, Universitas Negeri Surabaya, Indonesia

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Journal on Smart Learning Technologies
Volume 2, No. 2, 2026: 46 - 56
E-ISSN: 3109-9122
DOI: https://doi.org/10.26740/jslt.v2i2.53522

Navigating Digital Learning in the Infrastructure Gap: Adaptive PjBL Strategy in the RPL Department of Vocational High Schools

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Abstract

Digital transformation in vocational education often encounters systemic barriers, particularly in resource-constrained settings where infrastructure gaps significantly contrast with industry demands. This study aims to analyze the navigation of Project-Based Learning (PjBL) strategies and technological adaptation in a Software Engineering (RPL) program facing extreme device scarcity. A qualitative descriptive case study was conducted at SMKN Takeran, Indonesia, involving one productive teacher and 36 students. Data were gathered through participatory observation, semi-structured interviews, and document analysis, subsequently processed using thematic analysis. The findings reveal that a device ratio of 1:12 does not halt digital transformation but instead triggers "adaptive collaboration" and "pedagogical resilience." Students developed organic resource-sharing mechanisms, while teachers innovated through self-developed digital media to compensate for laboratory limitations. However, a "competency paradox" emerges where local resilience creates a transition gap towards industry standards that prioritize individual technical autonomy. This research suggests that digital transformation in vocational settings should be redefined as a pedagogical-driven process rather than a hardware-centric one. It provides a strategic framework for policymakers to implement more inclusive digital initiatives in low-resource environments.

Keywords: Project-Based Learning (PjBL), Vocational Education, Digital Transformation, Resource-Constrained Settings, Software Engineering.

Article History:

Received	Review	Accepted	Published
January 2026	February 2026	March 2026	May 2026

INTRODUCTION

Digital transformation has triggered a fundamental paradigm shift in the global landscape of vocational education. The integration of digital technology is no longer positioned merely as a pedagogical support tool, but rather as a primary prerequisite for aligning graduates' competencies with the increasingly complex dynamics of industry needs (Hermansah et al., 2025; Zou et al., 2025). In this

Journal on Smart Learning Technologies
Volume 2, No. 2, 2026: 46 - 56
E-ISSN: 3109-9122
DOI: https://doi.org/10.26740/jslt.v2i2.53522

context, vocational education is required to produce a workforce that is not only excellent in technical skills, but also possesses high digital literacy and the ability to adapt to technological disruption (Imama et al., 2025; Kovalchuk et al., 2023). Therefore, the success of vocational institutions is increasingly determined by their capacity to integrate advanced technologies such as artificial intelligence and automation into the core curriculum in order to ensure graduates' job readiness (Ghosh & Ravichandran, 2024).

However, the urgency of digital transformation is not always accompanied by readiness for implementation in practice. Many vocational institutions still face significant systemic challenges, such as limited infrastructure, financial constraints, and unequal access to digital devices (Triono Ahmad et al., 2023; Wang, 2024). These issues become even more complex in tool-intensive study programs, such as Software Engineering (RPL), which ideally require continuous access to modern computing devices to support the mastery of programming competencies. The reality in many schools, especially in marginalized areas, shows the opposite condition, where inadequate device ratios directly hinder the achievement of 21st-century skills (Rizkylillah et al., 2025; Sudjimat et al., 2021).

In facing these limitations, adaptive learning approaches become an unavoidable necessity. One model considered highly promising is Project-Based Learning (PjBL), which has been empirically proven to increase student engagement and integrate theoretical knowledge with real-world practice through collaborative activities (Roemintoyo & Budiarto, 2023; Rozan et al., 2024; Yusuf et al., 2021). PjBL also contributes to the development of work-related character traits relevant to industry needs. Nevertheless, most previous studies have tended to examine the implementation of PjBL in contexts with relatively adequate resources. This indicates a significant gap in the literature regarding how PjBL strategies can be effectively navigated and adapted in schools with extreme infrastructure limitations (Rizkylillah et al., 2025; Yeri & Baylon, 2025).

Digital transformation has triggered a fundamental paradigm shift in the global landscape of vocational education. The integration of digital technology is no longer positioned merely as a pedagogical support tool, but rather as a primary prerequisite for aligning graduates' competencies with the increasingly complex dynamics of industry needs (Hermansah et al., 2025; Zou et al., 2025). However, this urgency is contrasted by a persistent and significant infrastructure gap at the national level in Indonesia. According to recent national data, although approximately 13,178 SMKs have gained internet access for learning purposes in the 2024/2025 academic year, a substantial proportion of vocational schools still suffer from inadequate digital infrastructure, including low computer-to-student ratios, unstable internet connectivity, and limited access to modern computing devices (Kemendikdasmen, 2025; BPS, 2024; Setiaji et al., 2025). This digital divide is further evidenced by regional disparities, with schools in eastern Indonesia showing markedly lower connectivity compared to western regions, thereby exacerbating inequalities in achieving 21st-century competencies (World Bank, 2025; Rahmawati et al., 2025). In tool-intensive programs such as Software Engineering (RPL), these limitations directly hinder students' ability to master essential programming and digital skills.

Based on this gap, this study aims to conduct an in-depth analysis of PjBL navigation strategies and forms of technological adaptation implemented in the Software Engineering department of vocational high schools with limited devices. The main focus of this study lies in exploring the phenomenon of pedagogical resilience, namely a condition in which infrastructure limitations actually trigger innovation in learning media by teachers and encourage the formation of adaptive collaboration models among students. Unlike previous studies that focused more on the provision of devices, this study offers an alternative perspective that the success of digital transformation in low-resource environments is more determined by the quality of pedagogical strategy adaptation than by the quantity of available infrastructure (Roemintoyo & Budiarto, 2023). Thus, the findings of this study are expected to provide conceptual and practical contributions, particularly for policymakers, in formulating digital transformation approaches that are more inclusive, contextual, and sustainable for vocational education institutions in marginalized areas.

METHODS

This study adopts a qualitative approach with a descriptive case study design to explore learning navigation strategies under conditions of limited infrastructure. This design was selected to comprehensively understand a *bounded* system, including the dynamics and complexities of implementing Project-Based Learning (PjBL) in the Software Engineering (RPL) study program (Yin, 2017). The main focus of the research is to provide an in-depth description of the processes, pedagogical adaptations, and experiences of the research subjects in a factual context without any manipulation of variables (Creswell & Poth, 2018).

The study was conducted at SMKN Takeran, Magetan, East Java, a vocational school that represents typical characteristics of low-resource settings in Indonesian vocational education. Participants were purposively selected (Patton, 2014) and consisted of one productive Software Engineering (RPL) teacher and 36 eleventh-grade students who were directly involved in project-based learning activities under severe infrastructure constraints (36 students sharing only three functional laptops). Data were collected in the school's computer laboratory to capture authentic interactions in a natural setting (Merriam & Tisdell, 2016). Acknowledging that a single-teacher case study carries a high risk of bias, member checking was rigorously conducted by sharing the interview transcripts and preliminary findings with the participating teacher on two separate occasions. The teacher was invited to verify the accuracy of the data, clarify meanings, and suggest corrections, with all feedback incorporated into the final analysis. In addition, peer debriefing sessions with two external researchers in vocational education were held to enhance confirmability and reduce researcher bias.

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Data were collected through triangulation techniques, including participant observation, semi-structured interviews, and documentation study to ensure the credibility of the findings (Creswell & Poth, 2018).

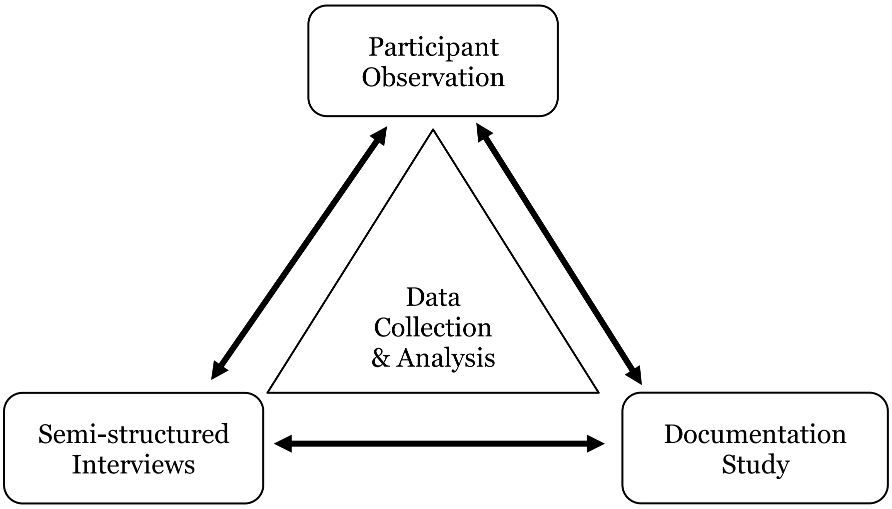

Figure 1. Data Collection Triangulation

Observation focused on adaptive collaboration activities and the use of self-developed learning media in the laboratory. Interviews were conducted using an open-ended guide to explore teachers' and students' perceptions regarding the effectiveness of PjBL strategies (Kallio et al., 2016). In addition, a documentation study was carried out on teaching instruments (lesson plans/RPP), curriculum drafts, and students' project outputs to validate the field data. Data analysis followed the interactive model of Miles, Huberman, and Saldaña (2014), which consists of three systematic stages: data reduction, data display, and conclusion drawing/verification.

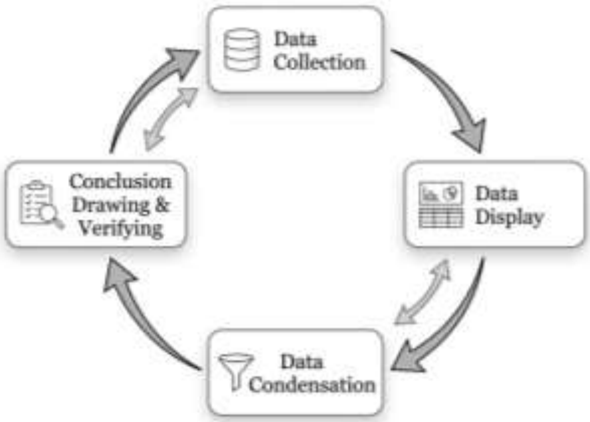

Figure 2. Interactive data analysis model adapted from Miles, Huberman, and Saldaña (2014).

At the reduction stage, raw data were categorized and coded based on themes of technological adaptation. Furthermore, the data were presented in the form of descriptive narratives and thematic tables to map patterns of relationships among research variables. To sharpen interpretation, a thematic analysis approach was used to identify pedagogical resilience and adaptive collaboration as the central themes. Data validity was tested through member checking and in-depth discussions with peers

RESULTS AND DISCUSSION

Based on observational data and in-depth interviews, the findings indicate that although there was an extreme device ratio gap (1 laptop for 12 students), the pedagogical process continued through complex adaptation mechanisms. This phenomenon was analyzed through four main dimensions: patterns of students' adaptive collaboration, the paradox of technical skill acquisition, teachers' resilience in innovation, and challenges in synchronizing with industry standards. Theoretically, this discussion integrates the concept of the digital divide (van de Werfhorst et al., 2022) with the TPACK framework under limited-resource conditions (Hermansah et al., 2025). The following explanation aims to deconstruct how human factors and instructional strategies are able to navigate physical barriers in order to sustain digital transformation in marginalized schools.

Adaptive Collaboration

The findings show that limited device availability (a 1:12 ratio) did not become an absolute barrier, but rather a trigger for sociocultural transformation in the classroom. A community of practice phenomenon emerged in which students developed an asymmetrical collaboration model. Unlike standard PjBL, which emphasizes equal task distribution, the low-resource context produced role distribution based on device access, namely the navigator (responsible for logic, algorithm planning) and the driver (responsible for code execution on the device). This adaptive collaboration model is illustrated in Figure 3.

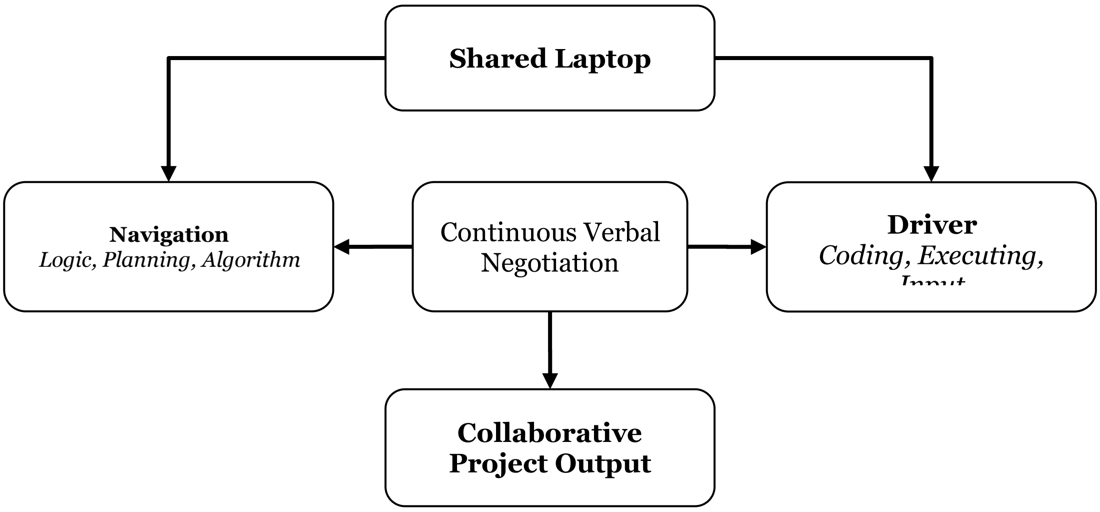

Figure 3. Adaptive Collaboration Role Model in Low-Resource PjBL

Figure 3 shows that limited devices encouraged the emergence of a two-layer work pattern, in which verbal interaction became the main component bridging conceptual thinking and technical execution. The navigator played a role in planning solutions and directing programming logic, while the driver translated these instructions into actual code. This pattern generated a process of continuous verbal negotiation that does not always appear in classrooms with an ideal device ratio.

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Observational data indicated a 45% increase in verbal interaction frequency compared to the control class with a 1:1 device ratio. This finding confirms that physical limitations actually stimulated more intensive cognitive negotiation, thereby strengthening communication and teamwork skills (Roemintoyo & Budiarto, 2023). Nevertheless, such collaborative structures also have the potential to create marginalization for students who are less dominant technically or socially (van de Werfhorst et al., 2022).

The Paradox of Digital Skills

A paradox was identified in the acquisition of digital skills. Although students' basic digital literacy improved through the use of mobile devices as substitutes (Imama et al., 2025), there was a gap in terms of technical depth. Students demonstrated relatively good conceptual understanding of software structures, yet showed limitations in debugging speed, coding efficiency, and independent exploration through direct practice. The position of this competency paradox is visualized in Figure 4.

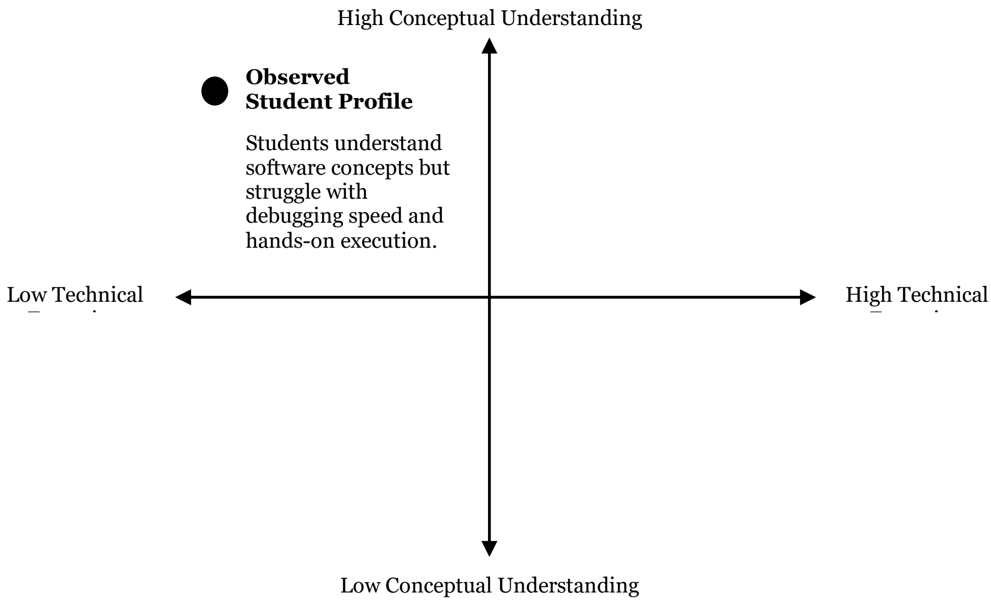

Figure 4. Digital Skills Paradox Matrix

Figure 4 maps the imbalance between conceptual and technical dimensions found in the study. Students' competency profiles were located in the quadrant of high conceptual understanding–low technical execution. This indicates that learners understood *what to do* in software development, but had not fully mastered *how to do it efficiently* according to industry demands. Limited device access reduced direct hands-on time, causing the automation of technical skills to develop slowly.

Analysis of students' project outcomes showed that the produced code tended to follow simple patterns replicated from teacher tutorials rather than resulting from independent exploration. This finding strengthens (Wang, 2024) argument that digital transformation without adequate infrastructure support risks creating an illusion of competence, a condition in which students appear to understand digital concepts but are not yet able to execute them efficiently in real-world situations (Riyanto et al., 2025).

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Pedagogical Resilience and TPACK Transformation

Teachers' strategies in navigating technological constraints through the creation of self-made tutorial videos and mobile-based modules represent a manifestation of pedagogical resilience. Teachers transformed infrastructure barriers into opportunities to implement contextual blended learning (Yusuf et al., 2021). Within the TPACK framework, teachers' pedagogical knowledge (PK) became the main determinant compensating for deficiencies in technological knowledge (TK).

However, this study found that teachers' cognitive load increased significantly. Teachers had to act simultaneously as instructional designers and infrastructure technicians. This phenomenon supports the argument of (Kovalchuk et al., 2023) that digitalization in marginalized areas depends heavily on educators' human capital. Without systemic policy support, this individual teacher resilience remains fragile and vulnerable to burnout.

Systemic Misalignment: The Industry-Ready Gap

The final finding of this study reveals the existence of a fundamental systemic misalignment between survival strategies in schools and performance expectations in the global industry. At SMKN Takeran, limited devices forced the emergence of a learning culture highly dependent on collective collaboration. However, in-depth analysis shows that this mechanism created a competency paradox: students became socially skilled in group coordination, yet experienced a deficit in technical autonomy. This poses a serious challenge to the *Link* and *Match* vision, where job readiness is measured not only by curriculum mastery, but also by adaptability to the software industry's work culture, which demands high individual efficiency (Riyanto et al., 2025).

This phenomenon can be explained through the emergence of a hidden curriculum caused by infrastructural poverty. When 36 students had to share only a few devices, the cognitive process that occurred was one of "distributed responsibility" (Sudjimat et al., 2021). Students who did not hold the device tended to become passive observers, resulting in weak muscle memory in coding and debugging. Consequently, when entering the Internship Program (PKL) phase, students experienced transition shock, a condition in which they struggled to adapt to individual workstations and strict performance deadlines. This multidimensional gap is summarized systematically in Table 1.

Tabel 1. Structural Misalignment Matrix between School Adaptation and Industry Expectations

Readiness Dimension	**Adaptive School Environment (Low-Resource)**	**Industrial Performance Environment (Standard)**	**Risk of Transition Disruption**
Infrastructure Access	Shared devices (1:12); limited access time	Individual workstations; full 24/7 access	Low workflow independence
Technical Execution	Guided coding with intensive teacher intervention	Autonomous coding based on technical documentation	Difficulty making independent technical decisions
Collaboration Pattern	Collective dependence (social solidarity)	Individual accountability within professional teams	Significant decline in personal productivity
Tools Environment	Simplified platforms (lightweight tools)	Complex Integrated Development Environments (IDE)	Steep learning curve when adapting to industry tools

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Outcome Orientation	Focus on process and task completion	Focus on efficiency and business metrics	Mental pressure from performance targets
Response Structure	Assisted troubleshooting (asking peers/teachers)	Independent debugging & self-research	Slow technical response to complex errors

Analysis of Table 1 reinforces that the local resilience developed by teachers and students was functionally effective as a temporary patch, yet professionally vulnerable. PjBL navigation strategies emphasizing group work, although pedagogically successful in the classroom, often obscured the assessment of individual competence. As emphasized by (Kebede et al., 2024), the relationship between vocational education and employability will remain fragile if students' learning experiences do not replicate real working environments.

Furthermore, these findings expand (Wang, 2024) critique regarding digital disparity: digital transformation in marginalized schools often stops at the stage of digital literacy and fails to reach the stage of digital professionalism. The unavailability of personal devices prevents students from engaging in deep exploration (deep work), which is an essential requirement in software development (Zou et al., 2025). Therefore, teachers' pedagogical resilience, although highly inspiring cannot be considered a permanent solution. More systemic policy interventions are needed, such as strengthening industry partnerships through cloud-based learning or virtual labs to mitigate physical laboratory limitations (Ghosh & Ravichandran, 2024). Without such measures, students in marginalized schools will remain trapped in a cycle of technical competency lag, despite possessing strong social capital.

CONCLUSIONS

This study reveals that Project-Based Learning (PjBL) in severely resource-constrained vocational education does not collapse under extreme infrastructure limitations; rather, it evolves through pedagogical resilience and adaptive collaboration. In the Software Engineering program at SMKN Takeran, the teacher and students successfully navigated a 1:12 device ratio by shifting from individual device-dependent practices to collective social capital through peer tutoring and smartphone-based self-directed learning. These findings affirm that successful digital transformation in marginalized vocational schools is driven more by pedagogical adaptability than by hardware availability. As a primary theoretical contribution, this study proposes the Adaptive Pedagogical Resilience Navigation Model (APRN Model), a visually mappable framework comprising contextual constraints, adaptive strategies (peer tutoring and media improvisation), enabling mechanisms (teacher flexibility and student collective intelligence), and dual outcomes (project success alongside the risk of competency paradox). This model offers both theoretical advancement and practical guidance for other low-resource vocational institutions seeking to implement meaningful digital learning. Nevertheless, the study cautions that while local resilience enables short-term achievement, it may create a transition gap when graduates enter industry environments demanding higher technical autonomy. Future research should examine the model's transferability across contexts to strengthen inclusive digital transformation policies in vocational education.

Author Contributions:
N.N.: Writing – Original Draft Preparation, Data Curation
A.A.C.: Writing – Review & Editing
I.S.: Writing – Review & Editing
M.U.A.: Writing – Review & Editing
Z.A.R.: Writing Final Draft, Review & Editing

Funding: This research received no external funding

Conflicts of Interest: The authors declare no conflict of interest.

Informed Consent Statement/Ethics approval: Not applicable

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Volume 2, No. 2, 2026: 46 - 56
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