An Integrated Digital Platform for Managing Vocational Teaching Factory: Design, Implementation, and Evaluation at Manado State Polytechnic

Antonius P.G. Manginsela | Ivonne H. Putong | Ottopianus Mellolo | Meiske Manoppo

ABSTRACT
The effective management of Teaching Factory (TEFA) activities in vocational education remains a challenge due to manual processes and disjointed academic systems. This study addresses these issues by designing, implementing, and evaluating e-TEFA, an integrated digital platform developed at Manado State Polytechnic. This research presents e-TEFA, a modular digital platform that leverages a service-oriented architecture built on the Laravel framework, RESTful APIs, and a MySQL database. The platform automates core Teaching Factory workflows, including student verification and grade synchronization through RESTful integration with the institution's Academic Information System (AIS). The platform's deployment led to a 90% reduction in project initiation time and eliminated data entry errors in grade reporting. A user-centered design approach was employed, resulting in high-fidelity prototypes for role-specific dashboards (students, lecturers, industry partners, leaders). System evaluation through black-box testing confirmed 100% functional correctness, while User Acceptance Testing (UAT) with 20 participants yielded an excellent average System Usability Scale (SUS) score of 84.0. Comparative analysis demonstrated significant improvements: a 90% reduction in processing time for project initiation, elimination of manual grade entry errors, and real-time reporting capabilities. The study concludes that e-TEFA effectively enhances operational efficiency, accuracy, and transparency in TEFA management. Future work will focus on developing a native mobile application and integrating financial modules aligned with Public Service Agency (BLU) policies to support broader institutional autonomy. Overall, this research contributes to advancing the digital transformation of vocational education by establishing a scalable model for integrating teaching factory operations with academic systems.

General Terms
Information Systems, Educational Technology, Software Engineering

Keywords
Teaching Factory (TEFA), Digital Platform, Vocational Education, System Integration, RESTful API, Operational Efficiency

1. INTRODUCTION
The State Polytechnic of Manado (polimdo.ac.id), a vocational higher education institution, has implemented a teaching factory (TEFA) model that integrates academic learning with production services in collaboration with industry partners. This approach allows students to benefit from hands-on experience in industrial activities while receiving guidance from lecturers. This practical engagement also constitutes a component of their academic assessment.

However, the management of TEFA activities continues to pose significant challenges, compounded by systemic implementation barriers identified in various Indonesian vocational contexts. Studies reveal persistent issues including scheduling conflicts, inadequate supervision, limited stakeholder alignment, and resource constraints [1] [2]. These operational hurdles, combined with technical fragmentation and lack of system integration, create a compounded challenge that demands holistic digital solutions. For instance, the process of student verification is inefficient, relying on manual checks that consume considerable administrative resources. Furthermore, the assessment process is fragmented, requiring lecturers to input grades into multiple, unintegrated systems, which creates redundant work and increases the risk of transcription errors.

Perhaps most critically, the lack of real-time reporting due to absent system integration means that project milestones, financial updates, and performance metrics are not available in real-time severely hampering decision-making. These challenges are compounded by the limited integration of most TEFA platforms with central academic systems like AIS, creating data disparities. To address these systemic inefficiencies, the development of an integrated, API-driven platform became essential to unify fragmented workflows and promote digital maturity within TEFA operations

In response to these challenges, this study proposes the design and development of an integrated digital platform, termed e-TEFA (Electronic Teaching Factory), to streamline the management of Teaching Factory activities in vocational higher education. The platform is designed to achieve the following specific objectives:

a. To automate student verification by integrating the system with the Academic Information System (AIS) through its API, enabling automatic validation of students' academic status and eligibility.
b. To facilitate seamless project and assessment management by providing a unified interface for lecturers to evaluate student performance and by automatically synchronizing assessment results with the central AIS gradebook, thereby eliminating manual data entry.
c. To provide real-time dashboards and analytical tools that offer institutional leaders and project managers comprehensive insights into project progress, financial metrics, and overall operational performance.
d. To establish a cloud-ready and scalable system architecture based on a microservices framework, enabling future expansion and integration of additional modules, such as a dedicated mobile application.

The e-TEFA platform is developed using a modular, service-oriented architecture (SOA). The backend is built with the Laravel framework, ensuring robust and maintainable codebase. For critical academic data synchronization, the system employs RESTful API to ensure seamless

interoperability with existing systems like AIS. Furthermore, a responsive user interface was prototyped using Figma to guarantee optimal user experience across devices.

To maximize flexibility and adoption, the platform is designed as a cloud-agnostic solution. This means it can be deployed on-premises or on major public cloud infrastructures (e.g., AWS, Google Cloud Platform), providing institutions with deployment choices based on their specific needs and policies.

The primary contributions of this research to the field of educational information systems are threefold:

a. A novel integrated architecture: this study proposes implementing a scalable architectural model that seamlessly bridges hands-on vocational training (TEFA) with core academic administrative processes, an area often characterized by operational silos.
b. A validated API-driven integration methodology: This study demonstrates the efficacy of a RESTful API-based approach in automating data exchange, significantly improving operational efficiency and eliminating redundant manual workflows in the educational domain.
c. Empirical performance evaluation: This study provides quantitative evaluation results that demonstrate the platform's success in increasing operational accuracy, reducing processing time, and enhancing transparency in TEFA management

Despite numerous studies addressing the integration of digital tools in education, most research on learning factories has primarily focused on training concepts and digital enablers in industrial or academic settings (e.g., Büth et al., 2018; Hulla et al., 2019) [3], [4]. However, there is still limited empirical evidence on how integrated digital platforms can systematically manage vocational teaching factories (TEFA) at the polytechnic level, especially in developing contexts.

Therefore, this study aims to bridge this research gap by developing and evaluating an integrated digital platform that manages TEFA operations, digital resources, and performance data in a unified environment. The platform is positioned as an enabler of digital transformation in vocational education, aligning teaching factory practices with Industry 4.0 competencies and digital readiness requirements.

2. RELATED WORKS

Research on the Teaching Factory (TEFA) model and educational technology has progressed along two distinct yet complementary trajectories: pedagogical-managerial evaluation and technological-infrastructural development. A critical synthesis of the literature, however, reveals a significant gap where these trajectories seldom converge, leaving the potential of digital integration to optimize TEFA management largely untapped.

Studies focusing on the pedagogical and managerial dimensions have extensively documented the benefits and implementation challenges of TEFA. For instance, Hastuti et al. (2025) [5] conducted a qualitative descriptive study on TEFA management within a Vocational High School Center of Excellence, analysing the functions of planning, organizing, actuating, and controlling. Their findings detailed a comprehensive management framework involving strategic industry partnerships via the 'Link and Match 8+i' strategy, product development based on competency achievement, and block scheduling for production continuity. Despite the reported success in enhancing student competencies, the study also identified persistent challenges, including resource constraints and the complexity of sustaining industry partnerships. Notably, their research underscored the manual nature of administrative processes—such as product recording, sales tracking, and reporting—which remain reliant on conventional methods like daily cash books and manual data entry, highlighting an area ripe for digital intervention.

Complementing this managerial perspective, Wahyudin et al. (2025) [6] employed a mixed-methods approach to explore industry-education collaboration within the TEFA model. Their research confirmed that TEFA significantly enhances students' practical skills, employability, and industry-academic ties. However, they also pointed to operational inefficiencies, such as difficulties in curriculum alignment and the resource-intensive nature of maintaining collaboration, which could be mitigated through technological solutions. These studies collectively establish a strong case for the pedagogical value of TEFA but stop short of proposing integrated digital systems to streamline its operations.

On the technological front, several researchers have developed information systems to address inefficiencies in educational and industrial training contexts. Prananda and Setiawan (2025) [7] designed and implemented a web-based TEFA information system for a digital media company to support student entrepreneurship programs. Their system, developed to overcome manual record-keeping and disjointed data management, featured modules for product recording, turnover monitoring, and SWOT-based business feasibility analysis. The study demonstrated the efficacy of a structured Software Development Life Cycle (SDLC) and the potential of such systems to improve data accuracy and facilitate real-time collaboration. However, the platform was tailored for a specific corporate context and did not address the need for seamless integration with a school's central Academic Information System (AIS), a critical requirement for holistic vocational education management.

The imperative for system integration in educational environments is well-articulated in the domain of information systems research. Sahara et al. (2022) [8] investigated the integration of Academic Information Systems (AIS) with Learning Management Systems (LMS) using RESTful Web Services and an external database architecture. Their design enabled real-time data synchronization, overcoming the perennial issues of data redundancy and manual updates that plague standalone systems. The study provides a robust technical blueprint for achieving interoperability between disparate platforms, emphasizing the advantages of a REST-based architecture for scalability and maintainability. This work is highly relevant, as the core challenge in TEFA digitalization is not merely building a standalone platform but ensuring it operates in unison with existing institutional systems.

Further contributing to the paradigm of digitalized industrial education, Mavrikios et al. (2017) [9] proposed a web-based application for classifying and managing the knowledge associated with Teaching and Learning Factories. Their platform utilized a three-tier architecture (data, business, presentation tiers) to create a unified database of facilities, application scenarios, and operational metrics. This approach underscores the importance of a structured, data-centric framework for managing complex educational infrastructures, aligning with the need for a centralized digital ecosystem in TEFA management.

Despite these advancements, a clear disconnect remains. Pedagogical studies like those of Hastuti et al. (2025) and Wahyudin et al. (2025) effectively outline the "why" behind TEFA's success but lack the "how" of technological execution. Conversely, technological studies such as Prananda and Setiawan (2025) and Sahara et al. (2022) demonstrate the "how" of building integrated systems but do not apply these solutions specifically to the nuanced, project-based, and

industry-collaborative workflows of a TEFA environment. None of the existing works have holistically addressed the automation of core TEFA workflows—such as student verification for project participation, real-time grade synchronization with the AIS, and consolidated reporting for lecturers and industry partners—within a single, integrated platform. Building on these findings, it becomes evident that both managerial and technological challenges coexist and must be addressed simultaneously within TEFA implementation.

While technological integration remains crucial for TEFA efficiency, several studies have examined TEFA implementation challenges in various vocational contexts. Dwijayanthi & Rijanto (2022) identified that despite adequate facilities and industry involvement in curriculum planning, the implementation system significantly affects student readiness. Their study at SMKN 2 Singaraja revealed that a rotational guard system in beauty salon TEFA activities proved less effective in developing critical thinking skills essential for workplace readiness. [1] This finding aligns with the operational challenges addressed by our e-TEFA platform, particularly in streamlining supervision and enabling more structured learning experiences. The study emphasizes the need for integrated learning models, including project-based approaches, to complement TEFA implementation—a gap our digital platform aims to address through automated workflow management and real-time monitoring capabilities.

The convergence of Teaching Factory concepts with Industry 4.0 technologies represents a paradigm shift in vocational education. Perwiranegara (2022) emphasizes that Industry 4.0 introduces revolutionary technologies including cloud computing, IoT, and data management systems that create new possibilities for knowledge sharing and training [2]. This aligns with Mavrikios' Teaching Factory paradigm which strives to integrate manufacturing education with contemporary industrial practice through two-way knowledge transmission between education providers and industry.

However, research reveals significant implementation gaps in the Indonesian context. Studies document that limited resources (both capital and technical expertise) and absence of common understanding among stakeholders hinder optimal TEFA implementation [2]. These challenges are particularly acute in the era of Industry 4.0, where digital transformation demands both technological infrastructure and organizational readiness.

The e-TEFA platform addresses these dual challenges by leveraging Industry 4.0 technologies (cloud architecture, RESTful APIs, microservices) while providing standardized frameworks that facilitate stakeholder alignment and optimize limited resources through digital efficiency.

3. METHODOLOGY

3.1 Research Design

This study employs a System Development Life Cycle (SDLC) approach, utilizing a hybrid Agile-Waterfall model. This methodology was selected to maintain the structured phases inherent in Waterfall while incorporating the iterative feedback cycles of Agile, thereby ensuring the final product aligns closely with stakeholder needs and allows for adaptive refinement throughout development. The research design is structured into five sequential yet iterative phases:

a. Requirement Analysis

This initial phase focused on comprehensively gathering both functional and non-functional requirements. The requirements were systematically elicited through structured interviews and workshops with key stakeholders, including lecturers, program coordinators, and industrial partners. Based on the analysis, six primary user roles were identified and profiled: Administrator, Lecturer, Student, Industrial Partner, Financial Officer, and Institutional Leader. Specific permissions and workflows were delineated for each role.

b. System Design

The design phase translated the gathered requirements into technical blueprints for the system. Low and high-fidelity interactive prototypes were developed using Figma, designed around the specific workflows of each user role to ensure usability and efficiency. The core data structure was formalized through an Entity-Relationship Diagram (ERD). Furthermore, the RESTful API endpoints for system integration were meticulously defined. A modular, microservices-based architecture was designed to ensure system scalability, maintainability, and facilitate future cloud deployment.

c. Implementation

The implementation phase translated the Figma prototypes into a functional system using Laravel 10, with specific modules for project management and assessment built as independent services. The server-side logic was implemented using Laravel 10, creating a robust set of RESTful API to handle all business operations. The web interface was built using the Laravel Blade templating engine and styled with Tailwind CSS to ensure a fully responsive design. A normalized MySQL 8 database schema was implemented to ensure data integrity and support scalability requirements. The system was developed as a Progressive Web App (PWA), providing a native app-like experience accessible from any device with a web browser.

d. Integration

A critical phase focused on ensuring seamless connectivity with the institution's existing academic ecosystem. An API Gateway was implemented to manage communication with the university's Academic Information System (AIS). Key integrated endpoints include GET /students/active to validate student eligibility status automatically, and POST /tefa-grade to synchronize project assessment grades directly to the central academic record. All data exchanges are secured using token-based authentication (OAuth 2.0 framework) to ensure secure and authorized communication.

e. Testing and Evaluation

The final phase rigorously assessed the system's functionality, usability, and performance. Black box testing techniques were applied to verify the functional correctness of all modules against the specified requirements. A group of end-users, comprising lecturers, students, and administrative staff, performed User Acceptance Testing (UAT) to validate the system's effectiveness in real-world scenarios. Key performance indicators, such as API response times and dashboard loading times for analytical queries, were measured to evaluate system efficiency under load. Following the evaluation phase, an additional mechanism was incorporated to ensure continuous improvement.

The proposed system design integrates a continuous feedback loop that enables real-time data acquisition, analysis, and improvement of teaching factory operations. Inspired by Büth et al. (2018) [3], who emphasized iterative learning cycles in digitalized training environments, the platform applies a similar principle to system monitoring. Data collected from user interactions and production activities are stored in a central repository and periodically analyzed to identify bottlenecks and inefficiencies. The platform’s analytics module generates

recommendations, which are fed back into the operational process, allowing instructors and students to iteratively improve task performance and production workflows. This cyclical feedback mechanism transforms the TEFA management process into a learning ecosystem where technological, pedagogical, and operational improvements reinforce each other over time.

3.2 System Architecture

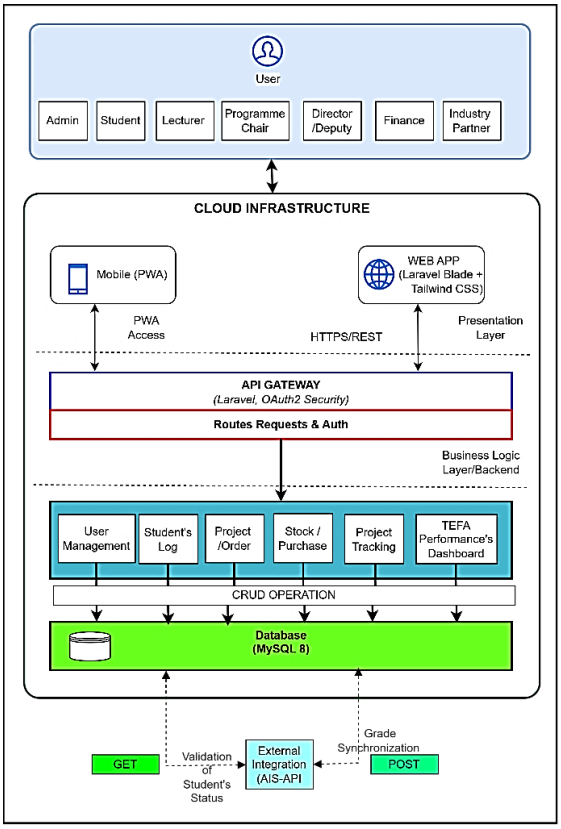

Fig 1: System Architecture Diagram

Following this design, the high-level system architecture of the e-TEFA platform. The design follows a microservices-based pattern, ensuring modularity and scalability. The Presentation Layer consists of a responsive web application and a Progressive Web App (PWA), both communicating with the backend via a secure RESTful API Gateway. The Application Layer is composed of independent services handling core functionalities such as assessment, reporting, and user management. The Data Layer centralizes information in a normalized MySQL database. A critical component is the secure integration with the external AIS via dedicated API endpoints (*GET /students/active*, *POST /tefa-grade*) to synchronize academic data. The entire system is designed to be cloud-agnostic, allowing deployment on various cloud providers or on-premises environments. Authentication across all layers is managed via the OAuth 2.0 protocol.

3.3 Database & API Integration

The e-TEFA database was designed with a normalized schema to ensure data integrity and avoid redundancy. The core entities and their relationships are illustrated in the simplified Entity-Relationship Diagram (ERD) in Figure 2, focusing on the integration with the academic information system.

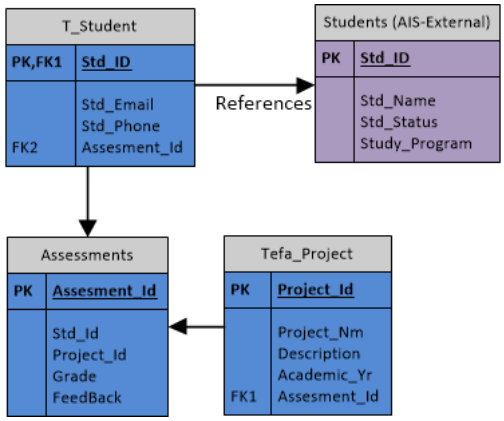

Fig 2 : A Simplified Entity-Relationship Diagram (ERD)

Figure 2, a simplified Entity-Relationship Diagram (ERD) highlighting the core data model for TEFA management and its critical integration with the Academic Information System (AIS). The students table in e-TEFA uses the *Std_Id* (Student ID) as a foreign key referencing the *Std_Id* entity in the external AIS database. This relationship enables seamless data validation and synchronization. The assessments table centralizes the evaluation results, linking students to their respective TEFA projects.

Table 1, API e-TEFA Integration With AIS

Endpoint	Method	Purpose	Input	Output
/students/active	GET	Verify student eligibility	Student ID, academic year	JSON: status
/tefa-grade	POST	Push TEFA grades into AIS	Student ID, grade, semester	JSON: success
academic-year/active	GET	Retrieve current academic period	None	JSON: period

The most critical aspect of the design is the seamless integration with the institution's existing Academic Information System (AIS). This was achieved by implementing a one-way synchronization mechanism through a dedicated API Gateway. e-TEFA consumes data from AIS for validation and, in turn, pushes back the results of the TEFA activities.

All data exchanges between e-TEFA and AIS are secured using the OAuth 2.0 client credentials grant flow. e-TEFA authenticates itself as a trusted client using a pre-shared *client_id* and *client_secret* to obtain an access token, which is then included in the Authorization header of every API request. This ensures that only authorized systems can send or receive academic data.

Student eligibility is checked when a student attempts to join a TEFA project; the system automatically calls the *GET /students/active* endpoint. The student's eligibility is confirmed only if the response returns to an "*active*" status. Upon final assessment by a lecturer, the system invokes the *POST /tefa-grade* endpoint. The payload contains the student's ID Number *Std_Id*, the course code linked to the TEFA project (*course-code*), the *Tefa-grade*, and the academic semester. This ensures the grade is immediately recorded in the student's official academic transcript within AIS.

This integration eliminates the need for manual data entry, thereby addressing the previously identified problems of

inefficiency, human error, and data disparity between practical training and academic records.

3.4 Tools & Technology

The development of the e-TEFA platform leveraged a modern technology stack designed for scalability, maintainability, and robust integration capabilities. The selection of tools and frameworks was driven by the requirements for a rapid development cycle, RESTful API architecture, and seamless frontend-backend integration. Table 2 summarizes the key technologies employed in this project.

Table 2, Technology Stack for e-TEFA Development

Layer/ Component	Technology	Purpose & Justification
Backend Framework	Laravel 10	Chosen for its elegant syntax, robust ecosystem, built-in API support, and powerful ORM
Frontend Framework	Laravel Blade + Tailwind CSS	Provides a simple templating engine and enables rapid building of modern, responsive UIs
Database	MySQL 8	Selected for its reliability, performance, and advanced features suitable for complex data
API Protocol & Architecture	RESTful API, Microservices	Adopted for simplicity, statelessness, and ease of integration; enhances scalability
UI/UX Prototyping	Figma	Used for designing high-fidelity interactive prototypes and facilitating stakeholder feedback
Version Control	Git / GitHub	Essential for collaborative development, version history, and code management.
Deployment Architecture	Shared Web Hosting, cPanel	Used for cost-effectiveness and ease of maintenance during initial development and testing
Cloud Platform	Cloud Web Hosting	Offers a balance of affordability, managed services, and scalability for the current stage
Programming Language	PHP	The core language for the Laravel framework, known for strong web development capabilities

The primary development was conducted using Visual Studio Code, leveraging its extensive extensions for PHP, Blade, JavaScript, and database management, which significantly improved developer productivity. The technology stack provided a balanced foundation between development efficiency, application performance, and long-term maintainability. For the initial deployment phase, the system was hosted on a managed cloud web hosting solution to optimize for cost-effectiveness and ease of setup while maintaining the potential for future migration to a more scalable infrastructure. This setup effectively supported the implementation and testing of all functional and non-functional requirements outlined for the e-TEFA platform.

4. RESULTS AND DISCUSSION

4.1 UI/UX Prototyping

The UI/UX design phase resulted in high-fidelity interactive prototypes developed in Figma, which served as a blueprint for development and facilitated early stakeholder feedback. The design prioritizes usability, role-based access, and a consistent visual hierarchy across all modules.

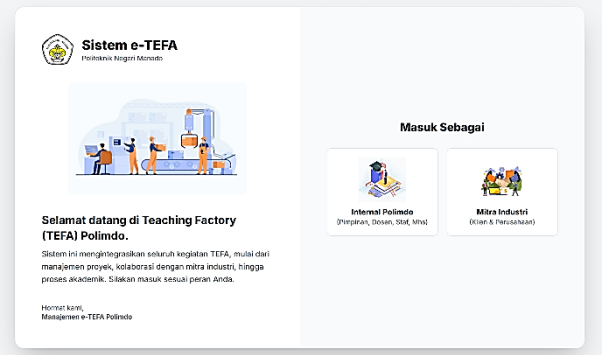

Fig 3: Landing Page e-TEFA's Single Sign-On Mechanism

The landing page shows different types of users externally and internally that will navigate them to the login page. Role-specific dashboards were designed for different user groups. The partner industry login page is different than the internal user's login page. Dashboard on each user's provides an overview of active roles on TEFA projects and tasks. Partner industry can track orders on their dashboard.

The internal users have their own dashboard according to their roles on eTefa.

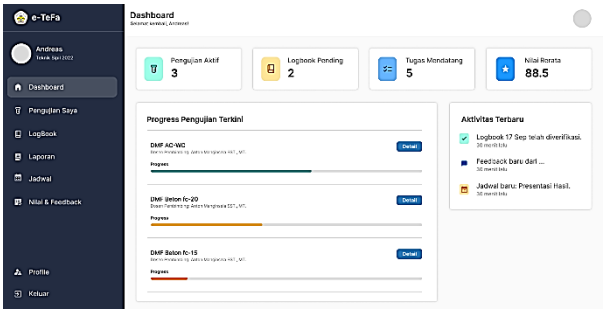

Fig 4: Student's Dashboard

The Student Dashboard provides an overview of active TEFA projects, tasks, deadlines, and recent feedback from lecturers.

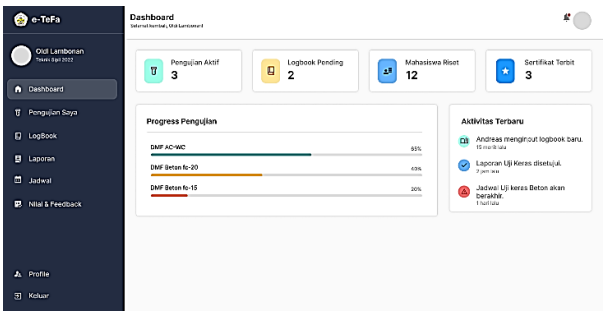

Fig 5: Lecturer's Dashboard

The Lecturer Dashboard centers on project management, student assessment interfaces, and monitoring project progress across different students and groups.

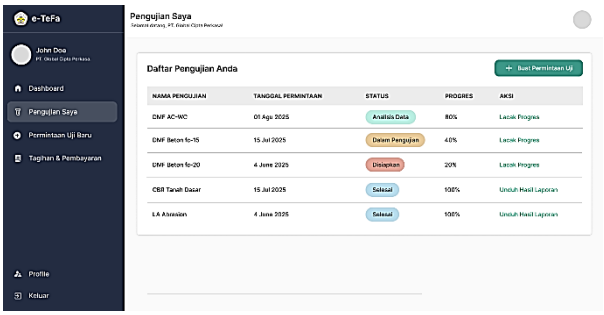

Fig 6: Industry Partner's Dashboard

The Industry Partner Dashboard offers tools for project collaboration, providing feedback to students, and tracking the overall progress of joint initiatives.

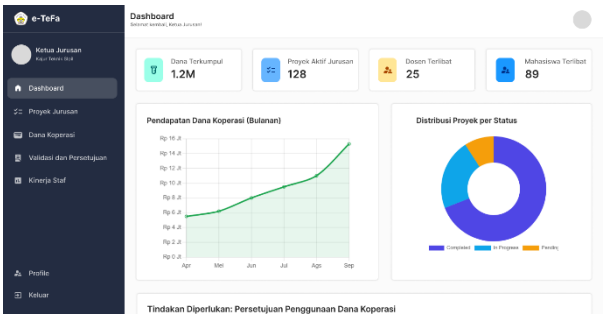

Fig 7: Leadership Dashboard

The Leadership Dashboard is designed for institutional leaders, featuring high-level analytics, real-time key performance indicators (KPIs), financial summaries, and graphical reports for strategic decision-making.

A dedicated Assessment Module interface allows lecturers to evaluate student performance based on predefined criteria, including form validation and support for both quantitative scoring and qualitative feedback. The Transaction Module streamlines the financial aspects of TEFA projects, enabling tracking of project-related income and expenditures.

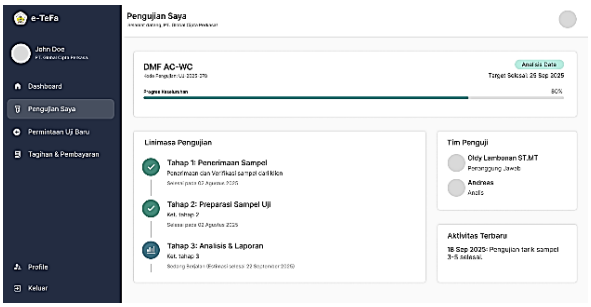

Fig 8: Transaction Module.

The prototyping phase successfully established intuitive user flows and a cohesive visual identity for the e-TEFA platform, ensuring that the final product would be user-centered and efficient for all stakeholder groups.

Based on the implementation results, the e-TEFA platform effectively addresses the resource optimization challenges identified in previous studies. The 90% reduction in project initiation time and elimination of manual errors directly counter the resource constraints documented by Perwiranegara (2022), while the excellent SUS scores (84.0) indicate success in overcoming the "common understanding" barrier through intuitive digital interfaces [2].

4.2 Implementation

The implementation phase successfully translated design prototypes into a fully functional system. The most critical technical achievement was the seamless integration with the institution's Academic Information System (AIS). AIS API Integration was implemented using a RESTful API Gateway within the Laravel backend. Two key endpoints were consumed to automate core academic processes: Student Verification (*GET /students/active*) automatically validates a student's academic status and eligibility before allowing them to register for any TEFA project, eliminating manual checks and ensuring data integrity. Grade Submission (*POST /tefa-grade*) automatically pushes the grade data to AIS upon finalization of an assessment by a lecturer, ensuring the TEFA grade is immediately reflected in the student's official academic transcript. The communication is secured via OAuth 2.0, with the system handling potential API failures gracefully with retry mechanisms and error logging. This implementation directly addresses the pre-identified problems of inefficient verification and disconnected grading processes.

4.3 System Evaluation

The functional correctness, usability, and practical effectiveness of the e-TEFA platform were rigorously evaluated through a combination of black-box testing and User Acceptance Testing (UAT) involving all key stakeholder groups.

Black box testing involved executing a comprehensive suite of test cases to verify that all functional requirements derived from the initial analysis were correctly implemented. The testing covered core workflows, including user authentication and role-based access control, project creation and management, the automated student verification process via AIS integration, the assessment input mechanism, grade synchronization with the academic system, and financial reporting. The black-box testing confirmed that 100% of the critical functional requirements operated as intended. The API integration with AIS proved particularly robust, achieving a 100% success rate in test scenarios for both student eligibility checks (GET */students/active*) and grade synchronization (*POST /tefa-grade*), with all data transmitted accurately and completely. This validates the technical reliability of the integration designed to eliminate manual data entry.

To evaluate the system's usability and practical acceptance from an end-user perspective, a UAT was conducted with a diverse group of stakeholders directly involved in the Teaching Factory ecosystem. Participants included lecturers, students, administrative staff, and industrial partners. Each participant was asked to complete a set of predefined, realistic tasks using the system, such as registering for a project, assessing student work, or reviewing project financials. Following the tasks, participants completed a standardized usability questionnaire based on the System Usability Scale (SUS).

The UAT yielded highly positive results, as detailed in Table 3. The overall average SUS score of 84.0 falls well within the "Excellent" acceptability range. A breakdown by user role reveals consistently high scores across all groups. Students (88.5) and Industrial Partners (85.5) reported the highest levels of satisfaction, praising the system's clarity and its effectiveness in facilitating collaboration and tracking progress. Lecturers (82.0) specifically highlighted the intuitive nature of the assessment module and the significant time savings achieved through automated grade synchronization.

Administrative Staff (80.0) confirmed the dramatic improvement in efficiency for student verification processes.

Table 3, User Acceptance Testing (UAT) Results

User Role	Number of Participants	Average SUS Score (0-100	Feedback Summary
Lecturers	5	82.0	The assessment module was intuitive and automatic grade synchronization saved significant time.
Students	5	88.5	Dashboard was clear; tracking project progress and feedback in one place was a major improvement
Administrative Staff	3	80.0	Student verification process became highly streamlined, reducing manual work and errors
Industrial Partners	4	85.5	Provided clear view into project progress and facilitated seamless collaboration.
Overall Average	20	84.0	Excellent Usability

The testing results from both evaluation approaches provide strong evidence that the platform works effectively in real-world conditions

The impeccable black box testing outcomes prove to be technically reliable and functional correctness. More significantly, the consistently high UAT scores across diverse stakeholder groups indicate not merely functional adequacy but superior usability and stakeholder acceptance. This dual validation through technical and user-centric evaluation frameworks provides compelling evidence for the platform's readiness for institutional deployment. Based on the comprehensive evaluation, it is confirmed that e-TEFA successfully addresses the main operational and usability challenges identified at the beginning of this study. The notably high satisfaction ratings from industrial partners (SUS score: 85.5) carry particular significance, as they demonstrate the platform's efficacy in bridging the theory-practice divide between academic and industrial domains—a fundamental principle of the Teaching Factory paradigm. This successful mediation between educational institutions and industry stakeholders represents a substantial contribution to vocational education technology. Beyond operational benefits, e-TEFA contributes to institutional digital maturity by embedding key Industry 4.0 principles such as automation, interoperability, and real-time analytics into vocational education management. This aligns with the global shift toward data-driven, adaptive learning ecosystems. Overall, these findings confirm the platform’s effectiveness in addressing key operational inefficiencies, as further quantified in the comparative analysis below, a finding that directly informs.

4.4 Extended Evaluation

To further strengthen the evaluation of the proposed e-TEFA platform, an extended assessment was conducted by examining system behavior under multiple operational scenarios commonly encountered in Teaching Factory (TEFA) activities. This evaluation was designed to move beyond a single usage condition and to reflect realistic variations in users, workflows, and operational processes within a vocational education environment.

The evaluation was carried out using representative operational data collected during a pilot implementation phase. For each core sub-process of the system, approximately ten records were used to simulate typical TEFA activities. These records covered a wide range of operational entities, including students, lecturers, industry partners, administrative staff, and managers, as well as diverse TEFA units such as electrical engineering, civil engineering, mechanical workshops, networking laboratories, culinary services, and retail-based teaching factories.

Three practical operational scenarios were considered. The first scenario represents a small-scale TEFA operation, in which a limited number of students and lecturers were involved in a single TEFA project. This scenario focused on validating basic system workflows, including student eligibility verification, project registration, logbook submission, and assessment entry. The system successfully processed all activities without errors, confirming functional correctness in low-load conditions.

The second scenario reflects a medium-scale operational setting, where multiple TEFA units operated concurrently. In this scenario, several sub-processes—such as industry order management, inventory updates, purchasing requests, and financial transactions were executed in parallel. Observations from this scenario indicate that the platform maintained consistent performance and data integrity, with no duplication or loss of information during concurrent operations. Role-based dashboards functioned as intended, enabling lecturers, staff, and industry partners to monitor progress and update records efficiently.

The third scenario simulates a peak operational period, characterized by overlapping academic and operational activities, including student assessments, industry service orders, payment processing, and reporting tasks. Despite increased activity, the system demonstrated stable responsiveness. Automated integration with the Academic Information System (AIS) consistently returned accurate student status information, while grade synchronization processes were completed successfully without manual intervention.

In addition to system-level performance, usability was observed across different stakeholder roles. Students and industry partners benefited from real-time access to project and order information, while lecturers and administrative staff reported reduced workload due to automated verification and grading processes. These observations suggest that the platform effectively supports diverse user needs across varying operational contexts.

Overall, the extended evaluation demonstrates that the e-TEFA platform performs reliably across different operational scenarios and workflow conditions. Although the evaluation was conducted within a pilot deployment scope, the results indicate that the system can support varied Teaching Factory implementations while maintaining operational efficiency, data accuracy, and user acceptance. This confirms the platform’s suitability for broader adoption in vocational education

institutions with similar organizational and operational characteristics.

Table 4. Performance Evaluation across Different Operational Scenarios

Operational Scenario	Evaluation Focus	Observed System Performance	Key Findings
Small-scale TEFA Operation	Core workflow validation (student verification, project registration, logbook entry, assessment submission)	All workflows executed successfully with stable response times	System functions correctly under low-load conditions and supports fundamental TEFA processes without errors
Medium-scale Concurrent Operation	Parallel execution of multiple sub-processes (orders, inventory, purchasing, assessments, payments)	No data duplication or loss observed; role-based dashboards updated correctly	Platform maintains data integrity and consistent performance during concurrent operations across multiple TEFA units
Peak Operational Period Simulation	High activity involving overlapping academic and operational tasks	System responsiveness remained stable; AIS integration performed reliably	Automated verification and grade synchronization remained accurate under increased activity
Cross-role Usability Observation	Interaction across different user roles (students, lecturers, staff, industry partners)	Positive usability feedback across roles	Role-based access and dashboards effectively support diverse stakeholder needs
Integration of Reliability	API-based data exchange with Academic Information System (AIS)	Successful execution of eligibility checks and grade synchronization	RESTful API integration ensures reliable interoperability with central academic systems

4.5 Comparative Analysis

A comparative analysis was conducted to quantify the improvements offered by the e-TEFA platform compared to the previous manual-based process. The results are summarized in Table 5.

Table 5, Comparative Analysis: Manual Process vs. e-TEFA Platform

Aspect	Manual Process	e-TEFA Platform	Improvement / Impact
Input Order / Project Initiation	Paper-based forms, physical signatures, manual data entry.	Digital workflow with automated notifications and approval chains	~90% reduction in processing time; elimination of physical document loss.
Project Tracking	Dispersed communication, no centralized view	Real-time dashboard showing progress, tasks, milestones.	Enhanced transparency and accountability; centralized information
Student Assessment Input	Manual entry, then re-entry into AIS	Fully automated via API integration; real-time eligibility check.	Elimination of redundant data entry; 100% reduction in transcription errors.
Student Validation	Manual cross-referencing with academic lists.	Real-time dashboards with automated analytics and reports.	Near-instantaneous verification; freed up administrative resources.
Leadership Reporting	Manual compilation, prone to delays and inaccuracies.	Real-time dashboards with automated analytics and reports.	On-demand access to accurate data for faster, data-driven decision-making.

The results clearly demonstrate that the e-TEFA platform provides substantial improvements across all operational aspects. The most significant impact is observed in processes involving data duplication and integration, such as student assessment and validation, where automation has virtually eliminated manual effort and errors. This validates the core hypothesis that an integrated digital platform can

effectively streamline TEFA management and enhance operational efficiency in vocational education. a finding that directly informs the concluding recommendations in the following section. The near-total elimination of manual errors in grade entry was a significant achievement; however, the study's evaluation period was limited to one academic semester. Long-term data collection is necessary to fully assess the sustainability of these improvements.

5. CONCLUSION AND FUTURE WORK

5.1 Conclusion

This study designed, developed, and evaluated e-TEFA, an integrated digital platform for managing Teaching Factory operations in vocational higher education. The evaluation results show clearly that the platform significantly enhances operational efficiency by systematically addressing the longstanding challenges of manual processes, functional fragmentation, and inadequate integration with central academic systems that have historically constrained TEFA program effectiveness.

The principal contributions of this research are threefold:

1. *Operational Efficiency Transformation*: Through the automation of critical workflows, including student verification and grade synchronization via secure RESTful API integration with AIS—the platform achieves substantial reductions in administrative overhead and processing timeframes.
2. *Data Integrity Advancement*: The implementation of seamless data exchange mechanisms eliminates redundant manual entry, thereby minimizing anthropogenic errors and ensuring unprecedented accuracy in academic records and project assessments.
3. *Architectural Integration Excellence*: The adoption of a modular, microservices-based architecture provides a scalable and robust foundation, with demonstrated success in bridging the gap between practical, industry-based learning and formal academic administration systems.

The compelling outcomes from User Acceptance Testing, evidenced by an exceptional overall SUS score of 84.0 across all stakeholder cohorts, including notably industrial partners, affirm that e-TEFA represents not merely a technically proficient solution but a pedagogically aligned and widely accepted educational technology intervention. Consequently, e-TEFA emerges as a validated instrument for streamlining TEFA management, enhancing operational transparency, and ultimately enriching the quality of experiential learning for vocational education students.

The successful implementation of e-TEFA at Manado State Polytechnic establishes a replicable model for vocational institutions across Indonesia and comparable contexts seeking to digitalize practice-oriented, industry-embedded learning models while maintaining robust integration with existing academic infrastructure.

In line with Büth et al. (2018) [3], the implementation results demonstrate that digitalization not only enhances the efficiency of operational management but also transforms the pedagogical dynamics of vocational training. The real-time monitoring and feedback capabilities of the platform increase transparency and accountability in learning outcomes, allowing students to understand the impact of their decisions within simulated industrial contexts. Furthermore, user evaluation results indicate a positive perception of the platform's usability and its potential to improve coordination among instructors and learners. The findings confirm that integrating digital tools into vocational training environments promotes experiential learning, self-regulated performance assessment, and a deeper understanding of data-driven manufacturing processes.

While this study focuses on the implementation of a digital management platform in a specific polytechnic context, the underlying model can be generalized to other vocational institutions adopting the teaching factory approach. The modular architecture of the platform allows flexible adaptation to different industrial domains and educational frameworks. Future research may expand this work by incorporating intelligent learning analytics, predictive maintenance modules, or AI-driven evaluation systems to further enhance digital maturity in vocational education.

While the current evaluation was conducted during an initial deployment phase, future longitudinal studies over multiple academic cycles will provide deeper insights into long-term system performance, scalability, and sustainability.

The findings underscore that integrating TEFA with institutional digital ecosystems can accelerate Indonesia's vocational education reform toward sustainable, industry-linked innovation

5.2 Future Work

Despite the effectiveness demonstrated by the current e-TEFA implementation, several strategic directions remain open for future enhancement to extend the platform's functionality and long-term impact. One important avenue involves the development of a dedicated native mobile application. While the existing Progressive Web App provides basic mobile accessibility, a native application would enable advanced features such as push notifications for critical deadlines, offline data collection in workshop and industrial environments, and a more optimized user experience for mobile-centric usage patterns. This direction is supported by user feedback indicating the need for reliable system access in settings with limited network connectivity.

Another promising direction concerns deeper integration with institutional financial systems, particularly within the framework of Public Service Agency (Badan Layanan Umum/BLU) policies increasingly adopted by Indonesian vocational education institutions. Future enhancements may include budget management, real-time project costing, automated invoices for industry partners, and financial reporting aligned with BLU accountability requirements. Such integration would provide institutional leaders with a more comprehensive view of both academic and financial performance across Teaching Factory units, supporting sustainability and evidence-based decision-making.

Collectively, these future developments are expected to evolve e-TEFA from a digital management tool into a more comprehensive platform that addresses the academic, collaborative, and financial dimensions of Teaching Factory operations. As the platform continues to mature, longitudinal evaluation across multiple academic cycles will be essential to further assess long-term performance, scalability, and institutional impact under varying infrastructure conditions.

6. ACKNOWLEDGMENTS

The authors express their appreciation to all participants and stakeholders at Manado State Polytechnic who contributed to this research.

7. REFERENCES

[1] K. D. Dwijayanthi and T. Rijanto, 2022. Implementation of Teaching Factory (TEFA) in Vocational School to

Improve Student Work Readiness, JOVES-Journal of Vocational Education Studies,(5/1 2022), 61-71.

[2] A. A. Perwiranegara, 2022. Teaching Factory Management in the Industrial Era 4.0 in Indonesia,International Journal of Science and Society, (4/ 3 2022). 151-162.

[3] L. Büth, S. Blume, G. Posselt and C. Herrmann, 2018. Training Concept For And With Digitalization In Learning Factories: An Energy Efficiency Training Case in 8th Conference on Learning Factories 2018-Advanced Engineering Education & Train for Manufacturing Innovation, Patras, Greece,

[4] M. Hulla, M. Hammer, H. Karre and C. Ramsauer, 2019. A case study based digitalization training for learning factories, in *9th Conference on Learning Factories*, Braunschweig, Germany.

[5] E. Hastuti, N. A. N. Murniatia and I Made Sudanaa, 2025. Teaching Factory Management at Vocational High Schools Center of Excellence in Temanggung Regency, Jurnal Dimensi Pendidikan dan Pembelajaran Universitas Muhammadiyah Ponorogo, (13/1 2025), 48-64. in press.

[6] D. Wahyudin, I. Hanafi and M. Ahmad, 2025. Enhancing vocational education through the teaching factory model: A study on industry-education collaboration, Edelweiss Applied Science and Technology, (8/2 2025) 1747-1758, in press.

[7] Cepi Prananda and Rony Setiawan, 2025. Design And Development Of A Teaching Factory (Tefa) Information System In Chlorine Digital Media Company To Support Vocational High School Entrepreneurship Programs, Jurnal Pendidikan Indonesia, (6/4 2025), 2745-7141,in press.

[8] R. Sahara, S. Abdullah, M. I. Saputra and C. R. Hassolthine, 2023 Integration Design of Academic Information Systems and Learning Management Systems Using Web Services Rest-Based External Database, Jurnal Ilmiah Fifo, (14/2 2023), 205-2015.

[9] D. Mavrikios, K. Sipsas, K. Smparounis, L. Rentzos and G. Chryssolouris, 2017 A Web-based Application for Classifying Teaching and Learning Factories, in 7th Conference on Learning Factories, Bolzano, Italy.