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Designing Integrated Inventory Learning in Logistics Vocational High School

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Abstract

The logistics industry is rapidly developing, providing opportunities for vocational high school/Sekolah Menengah Kejuruan (SMK) students majoring in Logistics Engineering to fill various occupational roles. Inventory is one of the logistics activities studied by SMK Logistics Engineering students. Learning that does not align with real industry conditions becomes an obstacle for students in understanding what needs to be done. This research aims to design interactive and integrated inventory learning for logistics. The research method used is a qualitative approach with Focus Group Discussions (FGD) as the primary data source, conducted with stakeholders including logistics vocational teachers, logistics experts, practitioners, students and lectures, along with secondary data from the logistics curriculum for SMK. The results indicate that there are six main cores that need to be incorporated into inventory learning, which include Concept and Flow, Inventory Control Methods, Cost Structure, Actual Case Studies, Related Documents, and Reporting Mechanism. Inventory learning will be more integrated if technology is used as an interactive and engaging learning aid, helping students fully and accurately understand inventory activities.

1. Introduction

Digital technology is the main key to entering the world of work in the Industrial 4.0 era (M. Ghea, 2018; Marimuthu, 2017; World Economic Forum [WEF], 2024). In the logistics and supply chain sector, technologies such as cloud computing, automation, robotics, artificial intelligence, and real-time data systems have increasingly transformed operational processes and workforce requirements (M. Ghea et al., 2018; Skitsko, 2016; McKinsey Global Institute, 2024). An example is the sharing concept, ranging from startup-based approaches such as Grab and Gojek implementing last-mile delivery models to more formal inter-company collaborations supported by digital platforms. This digitalization has reshaped customer expectations toward faster, more flexible, and cost-efficient logistics services (Kovács & Pató, 2014; OECD, 2024). Both individuals and businesses expect faster, more flexible services, with consumers increasingly demanding low or zero shipping costs, particularly in the logistics sector.

Various technological advancements have accelerated the transition from human-based operations to automation and robotics, which must be responded to positively in the education sector (Singh et al., 2018; UNESCO, 2024). Consequently, the demand for digitally competent logistics professionals continues to rise, emphasizing not only operational knowledge but also data literacy, automation awareness, and adaptive problem-solving skills (Moldovan, 2020; European Commission, 2024). This issue has been widely studied regarding the need for Vocational High Schools (Sekolah Menengah Kejuruan/SMK) to produce graduates who are ready for emerging industrial trends, while the availability of skilled logistics professionals remains insufficient to meet industry demand (Winkelhaus & Grosse, 2020; World Bank, 2024). Employment in the transportation and warehousing sector ranks among the largest employment contributors, reflecting the strong labor absorption capacity of the logistics sector (Pozzo et al., 2022; International Labour Organization [ILO], 2024). This indicates significant workforce absorption potential for SMK logistics graduates; however, curriculum–industry alignment remains a critical challenge.

However, many students face difficulties in understanding logistics learning materials, particularly in practical activities such as inventory management. Inventory is a core activity closely related to logistics industry operations. Therefore, the relationship between teaching and learning using technology should be closely aligned with real industrial activities (Schodl & Eitler, 2019; WEF, 2025). Learning can be supported through e-modules integrated with real industrial cases (Danirmala, 2020; Dankbaar et al., 2017; Erna & Anwar, 2021; Haleem et al., 2024), which significantly improves students' understanding of complex logistics concepts. Integrated and interactive modules help align learning processes with intended outcomes (Anwar et al., 2023). Recent studies further emphasize that vocational education requires technology-enhanced, industry-based learning experiences to ensure graduates possess job-ready skills in logistics and supply chain sectors (Fadieny & Fauzi, 2021; OECD, 2025). In response to this identified competency gap, this study proposes the development of an integrated inventory e-module grounded in Guy's exogenous–endogenous–process framework. The framework serves as a conceptual bridge linking external industry demands (exogenous factors), internal curriculum structures (endogenous factors), and pedagogical mediation (learning process)

2. Methods

In this study, the researchers employed descriptive research with a qualitative approach. More specifically, this study adopted a descriptive qualitative design aimed at exploring the alignment between logistics industry competency requirements and vocational learning outcomes. The research began with collecting and analyzing secondary data in the form of the Merdeka curriculum for the Logistics Engineering public vocational school (SMKN), followed by qualitative (open-ended) data collection. The qualitative approach was used to obtain an empirical picture of the competencies demanded by the labor market by evaluating Learning Outcomes. This study conducted over a period of 10 months, at SMK of Logistics Engineering Study Program in West Java and East Java. Participants were selected purposively to ensure disciplinary relevance and perspective diversity. The FGD involved vocational teachers, logistics practitioners, association representatives, academics from Indonesia and international institutions, as well as student representatives. The choice of homogeneity or heterogeneity of participants is adjusted according to the initial objectives of the Focus Group Discussion (FGD).

Therefore, considerations of heterogeneity involve variables such as teachers as learning facilitators in vocational schools, logistics practitioners from the industry with real-world experience in logistics, logistics associations that develop competency indicators and material needed in the logistics industry, and higher education academics focused on vocational logistics education. The homogeneity of FGD participants is determined based on their relevant field, which in this case is logistics. Heterogeneity considerations are made to obtain various perspectives on logistics from the viewpoints of researchers, teachers, practitioners, and logistics experts. This research uses the following data processing instruments: primary Data through Focus Group Discussion (FGD) with stakeholders. Secondary Data through drafts of the Logistics SMK curriculum.

This research is designed to gather information and data needed to determine the materials required for the design of e-modules for students at SMK of Logistics Engineering Study Program in West Java and Central Java. In this study, the researchers employed descriptive qualitative research to explore industry-relevant competencies required in the logistics sector and their alignment with vocational education learning outcomes. The research began with the collection and analysis of secondary data, followed by primary qualitative data collection through Focus Group Discussions (FGDs).

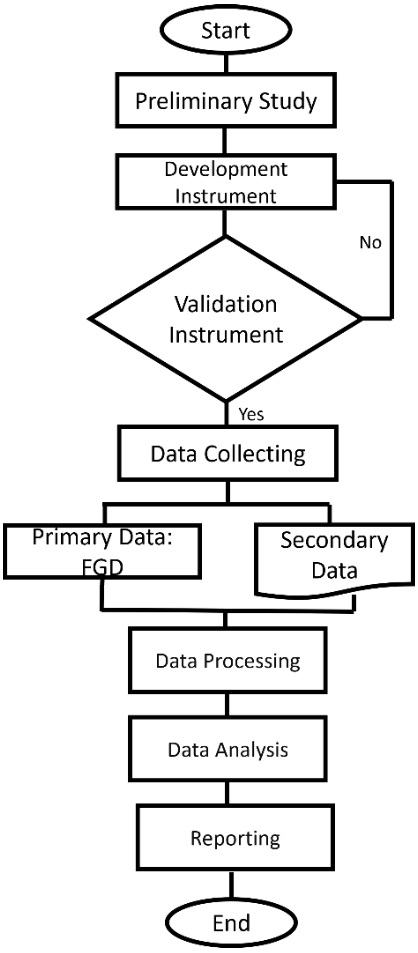

Fig. 1 *Research stages*

The overall research stages are illustrated in Figure 1. In FGD, researcher invited expert from several stakeholders like productive teachers in SMK of Logistics Engineering program in West Java and East Java as representative logistics teacher from vocational school. The other stakeholders are expert from Higher Education in Logistics field from United Kingdom (Conventry University), Germany (Jacob University), Indonesia (Universitas Logistik dan Bisnis Internasional), practicioner from Indonesia Logistics Association/Asosiasi Logistik Indonesia (ILA/ALI). Six experts provided for designing the inventory module, comparative point of view from academic, practitioner, teacher. Other participants are two students and two lecturers in Logistics Engineering.

Data fatigue in focus group discussions refers to the phenomenon where participants may experience a decline in engagement or interest due to repetitive or overwhelming data during the discussion. To anticipate data fatigue, the FGD is led by a moderator who guides the discussion to ensure it follows the guidelines provided in the pre-prepared FGD questionnaire. The primary data were collected through Focus Group Discussions (FGDs) using a semi-structured interview protocol, which is referred to in this study as an FGD questionnaire because it consists of a structured list of guiding questions. The FGD instrument consisted of 12 open-ended questions grouped into four themes: (1) industry trends and competency demands; (2) gaps between vocational learning outcomes and industry needs; (3) essential inventory management competencies; and (4) expectations for technology-integrated learning modules. To anticipate data fatigue, the FGD is led by a moderator.

To minimize data fatigue and ensure consistency, discussions were moderated using structured guiding questions and controlled time allocation. Secondary data were collected to support and triangulate findings from the FGDs. The secondary data consisted of: official Merdeka Curriculum documents for the Logistics Engineering program issued by the Ministry of Education; draft competency standards and learning outcome documents developed by the national logistics vocational teacher association and curriculum implementation guidelines used by SMKN 1 Garut (West Java Province) and SMKN 4 Malang (East Java Province).

These documents were analyzed using document analysis techniques, focusing on: learning outcomes related to inventory and logistics operations, and competency indicators required at the vocational level. Alignment between curriculum objectives and industry competency frameworks FGD help researcher to get primary data, in secondary data researcher get curriculum from association of teachers in the field of logistics that active and using in SMKN Logistic Engineering. After the data collected, next stage is processing. Qualitative data were analyzed using thematic analysis guided by Guy's exogenous–endogenous–process framework. The data triangulation used includes theory triangulation and data source triangulation as efforts to increase validity and reliability by utilizing various sources and data. The last step is reporting in scientific article.

After data collection, qualitative data from FGDs and document analysis were processed and analyzed using thematic analysis. To enhance validity and reliability, the study employed data source triangulation (teachers, practitioners, academics, students) and theory triangulation through comparison with existing logistics and vocational education literature. The final stage of the research involved synthesizing the results to inform the design of an integrated e-module for inventory management in vocational logistics education.

3. Results

3.1 Inventory Learning in SMK Logistics Engineering

Industrial logistics engineering education must use a set of teaching and learning methods to provide tools for a lean and agile cooperation in interlinked networks and the digital interconnectivity of organizations. Summarizes teaching and learning as a complex process that is dependent from a multitude of endogenous and exogenous factors which can be seen on Figure 2.

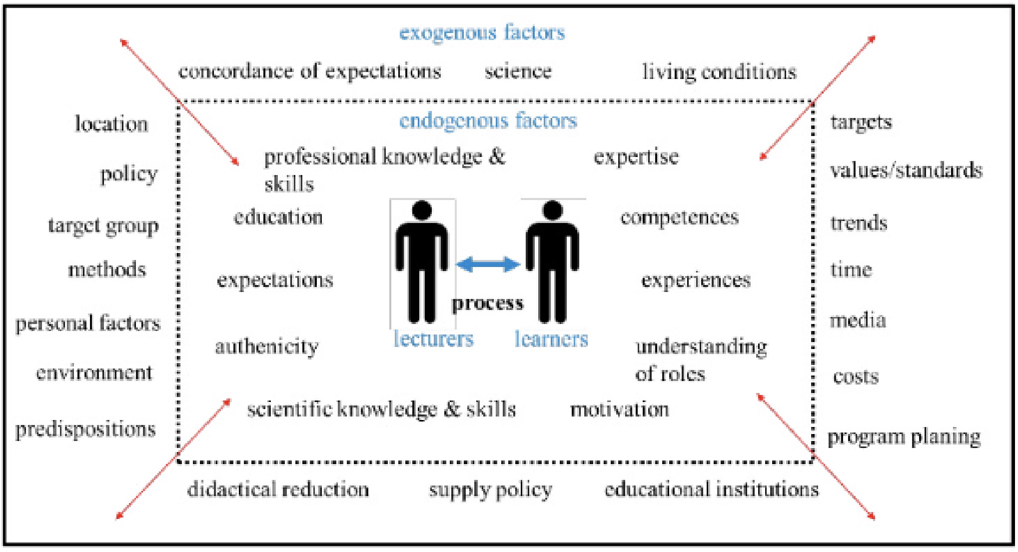

Fig. 2 *Adapted Guy's framework linking industry demands, educational competencies, and the learning process for integrated logistics e-module design. (Sources: Woschank, M., & Pacher, C., 2020)*

Guy's framework in Figure 2 adapted from Guy's exogenous–endogenous–process framework was employed as an analytical lens to systematically interpret competency requirements in logistics education and to align educational processes with industry demands. Rather than functioning as a measurement instrument, the framework served as a conceptual structure for organizing qualitative evidence derived from FGDs and document analysis. Exogenous factors—such as industrial trends, technological advancement, labor market requirements, and regulatory expectations—were examined through inputs from logistics practitioners, professional associations, and higher education experts. Endogenous factors, encompassing institutional competencies, pedagogical practices, and learning outcomes, were explored through vocational teachers and curriculum documents from SMKN 1 Garut (West Java Province) and SMKN 4 Malang (East Java Province). The interactional dimension of the framework, representing the teaching–learning process, captured pedagogical strategies, technology integration, and challenges in delivering inventory-related content. This analytical integration enabled the identification of competency gaps and instructional misalignments, thereby informing the design of an industry-aligned and pedagogically grounded e-module for logistics education. After data collection, thematic analysis was conducted by categorizing findings according to the three components of Guy's framework in table 1.

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Table 1 *Role of Guy's framework in data analysis*

Guy's Framework Component	Data Source	Findings
Exogenous factors	Industry experts, associations, policy documents	Demand for digital logistics skills, automation, real-time inventory systems
Endogenous factors	Teachers, curriculum documents	Gaps in competency coverage, limited contextual learning materials
Learning process	Teachers, students, FGDs	Need for interactive, case-based, and industry-integrated e-modules

Based on Table 1, following data collection, a thematic analysis was conducted by organizing the findings according to the three core components of Guy's framework: exogenous factors, endogenous factors, and the learning process. This analytical structure enabled a systematic interpretation of how external industry demands, internal educational conditions, and pedagogical practices interact within logistics education. The analysis revealed that exogenous factors—derived from industry experts, professional associations, and policy documents—highlighted a growing demand for digital logistics competencies, automation literacy, and real-time inventory management capabilities. These findings reflect the rapid transformation of logistics systems driven by technological advancement and evolving market expectations.

At the endogenous level, data indicated gaps in competency coverage. Particularly, contextual case integration and structured inventory sequencing were identified as insufficiently aligned with real industry practice. This suggests that existing instructional structures have not fully accommodated the dynamic skill requirements of the logistics sector. Meanwhile, analysis of the learning process, informed by inputs from teachers and students through FGDs, emphasized the need for interactive, case-based, and industry-integrated learning experiences to enhance conceptual understanding and practical competence, especially in inventory-related topics.

By mapping these empirical findings onto Guy's framework, the study established a coherent linkage between external demands, internal educational capacities, and pedagogical processes. This integrative mapping informed the design of the proposed e-module, which incorporates real industrial cases, current digital technologies, and structured learning activities aligned with targeted competencies. Consequently, the framework functioned as a conceptual bridge between empirical evidence and instructional design, ensuring that the resulting e-module is both industry-responsive and pedagogically grounded.

FGD took many insights from experts, teachers give some reason that technology is one of good tools for learning. The teachers showed that application of technology in learning at vocational high schools (SMK) has many benefits, that showed in Table 2.

Table 2 *Thematic analysis of FGD findings on the role of technology in vocational learning*

Code	Theme	Description / Interpretation	Representative Quotes (FGD)
C1	Improving Access to Learning Resources	Technology expands students' access to diverse digital learning materials, including e-books, online journals, video tutorials, and online courses, enabling broader exposure beyond printed textbooks.	*"Students can explore many learning sources independently, not only from textbooks but also from online materials related to logistics practices." (Teacher,SMK in West Java)*
C2	Interactive and Engaging Learning	Digital tools such as multimedia, simulations, and educational applications foster interactive learning environments that enhance conceptual understanding and learner engagement.	*"When learning uses simulations or videos, students understand logistics processes faster and are more engaged." (Teacher,SMK in East Java)*
C3	Development of Digital Skills	Technology use supports the development of digital literacy and technical competencies required in modern logistics workplaces, including familiarity with software and digital systems.	*"Students need to be familiar with logistics software and digital tools because these are used directly in industry." (Industry Practitioner)*
C4	Personalized and Adaptive Learning	Technology enables flexible learning pathways by allowing students to adjust	*"Some students need more time to understand, and digital modules allow*

Code	Theme	Description / Interpretation	Representative Quotes (FGD)
		learning pace and content according to individual abilities and learning styles.	*them to repeat materials independently." (Vocational Teacher)*
C5	Effective Collaboration and Communication	Online platforms facilitate collaboration, information sharing, and communication between students and teachers, supporting teamwork and knowledge exchange.	*"Group assignments are easier to manage through online platforms, and students communicate more actively." (Teacher,SMK in East Java)*
C6	Efficiency and Time Management	Learning management systems improve instructional efficiency by organizing materials, assignments, assessments, and feedback in a structured manner.	*"Using LMS helps us manage classes, assignments, and assessments more efficiently." (Teacher, SMK in West Java)*
C7	Simulation and Practical Training	Simulation-based learning provides realistic practice environments that resemble actual industry settings, particularly in logistics and technical operations.	*"Simulation tools help students understand real warehouse operations before entering industry." (Logistics Practitioner)*
C8	Increased Student Motivation and Engagement	Technology-supported learning environments increase students' motivation and active participation in the learning process.	*"Students are more motivated when learning involves technology rather than traditional lectures." (Student Participant)*
C9	Learning Anytime and Anywhere	Digital learning enables flexibility in time and location, allowing students to access learning materials beyond the classroom setting.	*"Students can study anytime and anywhere, especially when they use online platforms." (Teacher, SMK in West Jawa)*
C10	Better Monitoring and Evaluation	Technology enables real-time monitoring of student progress and supports more accurate and timely assessment through data-driven feedback.	*"With digital systems, we can monitor student progress and provide feedback more quickly." (Teacher,SMK in East Jawa)*

Table 2 presents the results of the thematic analysis, identifying ten key themes that describe the role of technology in vocational learning. Technology expands students' access to diverse learning resources, including e-books, online journals, and instructional videos (C1), while also fostering interactive and engaging learning environments through multimedia and simulations (C2).

Furthermore, technology supports the development of digital and professional skills relevant to the logistics industry, particularly in the use of software and digital systems (C3). It also enables personalized and adaptive learning, allowing students to learn at their own pace based on individual needs (C4). In addition, online platforms enhance collaboration and communication among students and teachers (C5), while learning management systems improve efficiency in organizing instructional activities, assessments, and feedback (C6).

Simulation-based learning provides practical experience through realistic logistics scenarios (C7). Moreover, technology increases student motivation and engagement (C8) and enables flexible learning across time and location (C9). It also facilitates more effective monitoring and evaluation through real-time feedback and data-driven assessment (C10). Overall, these findings highlight the critical role of technology in improving learning effectiveness, skill development, and instructional efficiency in vocational education. The conceptualization of an integrated e-module that covers multiple logistics sectors in Indonesia is grounded in empirical input from FGD participants, including logistics practitioners and industry representatives. Participants identified the logistics landscape as highly heterogeneous, covering manufacturing, healthcare, agriculture, and humanitarian sectors. Thematic findings were categorized into exogenous, endogenous, and learning process dimensions. These findings indicate that an integrated e-module structured around realistic scenarios can enhance relevance, strengthen industry alignment, and support students in navigating the complexity of Indonesia's logistics ecosystem.

3.2 Designing E-Module Inventory Learning

Experts from industry and academia agree on the need for integrating learning into logistics activities that align closely with real industry conditions. For example, stock control procedures include: goods Receipt process that clear procedures for receiving and inspecting incoming goods. Storage and retrieval process is an organized system for the placement and retrieval of goods. It suitable as ither research showed that in interactive learning needs several real case from industry (Antonczak, L., Neukam, M., Bollinger, S., 2022). Additionally, data management and analytical skills are required, including using data to predict demand, identify trends, and make better decisions (Novak, A., Bennett, D., & Kliestik, T.,2021) as well as regular and detailed reporting to monitor inventory performance and status. The e-module will be structured into partial modules for each logistics sector. The e-module is structured as a sector-adaptive learning system, accommodating Indonesia's heterogeneous logistics ecosystem (manufacturing, healthcare, agriculture, humanitarian, retail, and e-commerce sectors). Additionally, this is in line with the future development direction of vocational schools (SMK) In Indonesia, which will begin to focus on the needs and potentials of each region, thereby expected to advance the emerging industries in each area. Each e-module package will include six main contents. The six core components were derived through cross-source thematic synthesis and represent the operationalization of exogenous industry demands into pedagogically structured learning units. The content of the e-module can be seen in Figure 5.

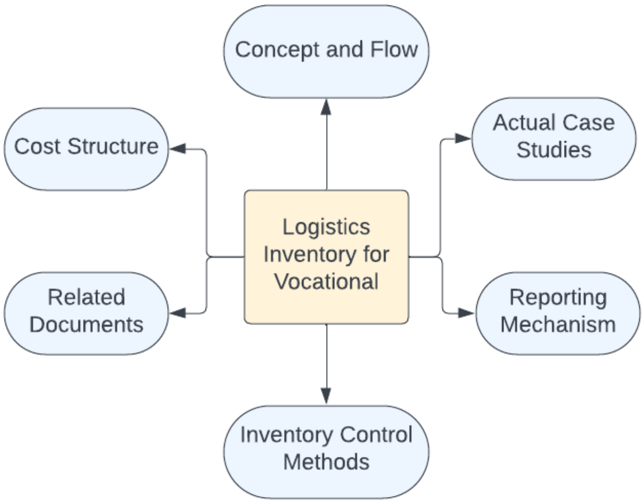

Fig. 5 *Inventory logistics e-module contents for each sector*

The development of Figures 4 and 5 was grounded in a systematic qualitative analysis guided by Guy's exogenous–endogenous–process framework. Data were collected through Focus Group Discussions (FGDs) with logistics practitioners, vocational teachers, academics, and industry association representatives, complemented by document analysis of the Merdeka Curriculum and logistics competency standards. Using thematic analysis, initial open coding identified recurring issues related to industry expectations, learning challenges, and competency requirements, which were subsequently organized through axial coding into exogenous factors (e.g., sectoral logistics demands), endogenous factors (curriculum structure and institutional capacity), and learning process dimensions (pedagogical strategies and learner engagement). This analytical approach aligns with recent qualitative design frameworks emphasizing theory-driven categorization and data–theory integration in vocational education research (Tynjälä, 2020; Cattaneo et al., 2022). Figure 4 synthesizes the exogenous dimension by mapping logistics sector diversity as articulated by industry stakeholders, while Figure 5 translates these demands into pedagogical components—such as inventory control, documentation, and real-case learning—representing the learning process dimension. This integration reflects contemporary approaches to vocational curriculum design that emphasize contextualized, industry-aligned, and adaptive learning systems (OECD, 2023; Zawacki-Richter et al., 2023; Ivanov & Dolgui, 2021). Consequently, the diagrams function as analytical constructs derived from empirical evidence, ensuring coherence between industrial requirements, educational processes, and instructional design. Figure 4 and Figure 5 constructed by Table 3.

Table 3 *Analytical pathway from data to diagram construction*

Data Source	Key Themes Identified	Mapping to Guy's Framework	Representation in Figures
FGD with logistics practitioners	Sector-specific operational needs; real-case exposure; industry documentation	Exogenous factors (industry demands)	Figure 4: Logistics sectors (manufacturing, healthcare, agriculture, etc.)
FGD with vocational teachers	Curriculum gaps; need for structured learning flow; assessment challenges	Endogenous factors (educational structure and competencies)	Figure 5: Concept & flow, inventory control, reporting
FGD with academics	Alignment between theory and practice; learning transfer	Learning process (pedagogical mediation)	Figure 5: Integration of case studies and learning activities
Curriculum & policy documents	Required competencies; learning outcomes; assessment standards	Endogenous–process linkage	Figure 5: Modular structure of e-module
Cross-source synthesis	Need for adaptive, industry-aligned learning	Integrated framework	Figure 4–5 combined conceptual model

Table 3 illustrates the analytical pathway through which empirical data were systematically transformed into the conceptual structures presented in Figures 4 and 5. The table demonstrates how multiple data sources—ranging from FGDs with key stakeholders to curriculum and policy documents—were synthesized through Guy's exogenous–endogenous–process framework to ensure analytical rigor and conceptual coherence. Rather than serving as isolated inputs, each data source contributed distinct yet interconnected insights that collectively informed the design of the integrated e-module.

Findings from FGDs with logistics practitioners primarily informed the exogenous dimension, highlighting sector-specific operational requirements, real-world logistics practices, and documentation standards. These insights directly informed Figure 4, which visualizes the diversity of logistics sectors and reflects industry-driven competency demands. In parallel, FGDs with vocational teachers revealed internal pedagogical challenges, such as curriculum gaps, fragmented learning flows, and assessment limitations. These inputs shaped the endogenous dimension, represented in Figure 5 through structured learning components such as conceptual sequencing, inventory control mechanisms, and reporting systems.

Insights from academic experts further strengthened the learning process dimension, emphasizing the need to bridge theoretical understanding and practical application through contextualized learning activities. This perspective informed the integration of case-based learning and experiential components within the e-module design. Additionally, curriculum and policy documents provided formal benchmarks for competencies and learning outcomes, reinforcing the alignment between institutional expectations and instructional design.

Through cross-source synthesis, the study identified a recurring need for adaptive and industry-aligned learning structures. This convergence of evidence enabled the formulation of an integrated conceptual model, in which Figures 4 and 5 jointly represent the translation of empirical findings into a coherent instructional framework. Consequently, the table demonstrates how the study moves beyond descriptive analysis toward a theoretically grounded and practice-oriented model for vocational logistics education

4. Results

4.1 Inventory Learning in SMK Logistics Engineering

Recent studies further reinforce the importance of aligning vocational education with dynamic industry ecosystems through integrative and technology-enhanced learning models. Recent evidence highlights that logistics education must increasingly emphasize digital competencies, data-driven decision-making, and adaptive problem-solving to remain relevant in the context of Industry 4.0 and emerging Industry 5.0 paradigms (World Economic Forum, 2023; OECD, 2024). Moreover, research indicates that learning designs grounded in authentic industry cases and supported by digital learning environments significantly enhance students' cognitive engagement and employability readiness (Haleem et al., 2024; UNESCO, 2024). The integration of industry-aligned competencies into vocational curricula has also been shown to reduce the skills mismatch between graduates and labor market expectations, particularly in logistics and supply chain sectors (European Commission, 2024).

Building on this premise, this study argues that the core challenge in inventory learning within SMK Logistics Engineering lies in the misalignment between external industry demands and internal educational practices. In this regard, the use of Guy's framework is not merely analytical but also strategic, as it provides a structured

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mechanism to bridge this gap. By integrating exogenous factors (industry expectations), endogenous factors (curriculum and institutional capacity), and the learning process (pedagogical practices), the framework enables a more coherent alignment between what is required in the workplace and what is delivered in the classroom. This alignment is critical to ensure that instructional design does not simply reflect technological trends, but actively contributes to sustainable workforce development.

The present findings extend existing discussions on technology integration in vocational education by demonstrating that technology should not be positioned as a supplementary tool, but rather as a central component of pedagogical transformation. Consistent with recent vocational education research, technology-enhanced learning environments are shown not only to expand access to instructional resources but also to foster pedagogical innovation and improve learning outcomes (e.g., Wiley et al., 2024; Tri Handayani et al., 2025). However, this study further argues that the effectiveness of such environments is contingent upon the alignment of three interdependent dimensions. First, from the exogenous perspective, industry-driven digital competency demands directly shape curriculum relevance and learning design (Imama et al., 2025). Second, at the endogenous level, institutional readiness and teacher competence emerge as decisive factors, indicating that technology integration is not merely a matter of infrastructure, but of pedagogical capability (Nature Scientific Reports, 2023; Firmansyah et al., 2025). Third, within the learning process, interactive and technology-mediated pedagogies—particularly those grounded in authentic tasks—are essential in fostering deeper engagement and meaningful skill acquisition (Wiley et al., 2024).

These theoretical connections underscore that effective integration of technology in vocational learning requires a holistic approach that simultaneously addresses external industry drivers, internal instructional capabilities, and learner–teacher interactions, thereby strengthening the framework's explanatory power in structuring both data interpretation and instructional design.

Several research in 2020 until 2024 showed that using technology help many students and teacher in an interactive learning (Gunawan, G., et.all., 2020). Beyond improving instructional quality, technology also plays a critical role in preparing students for participation in an increasingly digital and interconnected workforce. In parallel, industrial practices have begun to adopt virtual representations of real production processes for training purposes (Michlowicz, 2021). This development introduces the concept of the twin process, which highlights the interaction between virtual and real systems, as illustrated in Figure 3.

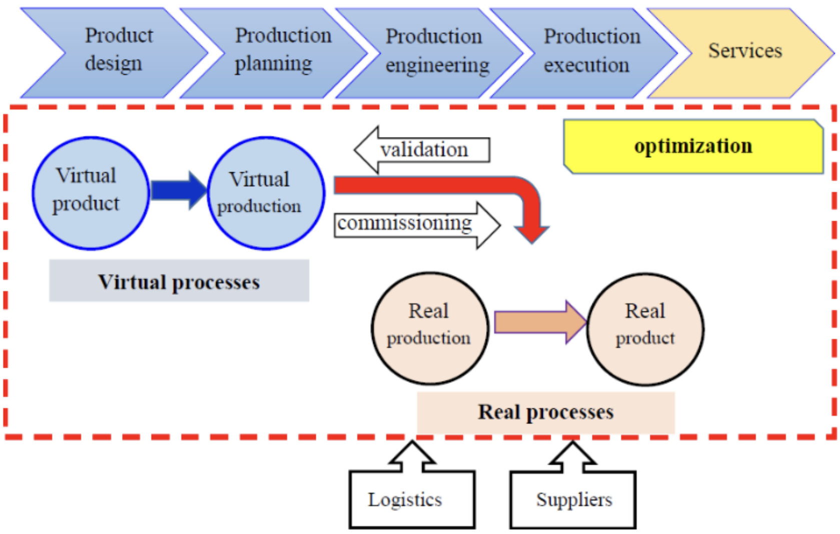

Fig. 3 *Twin processes in the Industrial 4.0 concept*
Sources: Michlowicz, E. (2021)

With these benefits, the application of technology in vocational learning not only enhances instructional quality but also supports students' readiness to operate in increasingly digitalized and interconnected industrial environments. The concept of twin processes proposed by Michlowicz (2021), as illustrated in Figure 3, conceptual illustration of twin processes in the Industry 4.0 framework, showing the interaction between virtual and real production systems (adapted from Michlowicz, 2021). In this study, the twin-process concept is used as an analytical analogy to explain how interactive e-modules function as pedagogical "digital twins," allowing students to simulate inventory decision-making before engaging in real industrial contexts.

This study advances this concept by repositioning the twin-process model as a pedagogical construct. Specifically, interactive e-modules are conceptualized as "digital twins" that simulate inventory decision-making processes within a virtual environment. This approach addresses a fundamental limitation in vocational education—namely, the difficulty of transferring theoretical knowledge into diverse and complex real-world contexts. The findings demonstrate that such simulation-based learning supports both cognitive and procedural skill development, as reflected in the high effectiveness score (84.72%) and strong student responses. In this sense, the e-module functions not only as a learning medium but as a critical bridge between theory and practice, analogous to virtual commissioning processes in Industry 4.0.

Furthermore, the challenges faced by logistics vocational students in Indonesia—especially in transferring theoretical knowledge to diverse industrial contexts—mirror the industrial need for alignment between virtual and real processes. As logistics sectors in Indonesia are distributed across multiple clusters with distinct operational characteristics, adaptive and modular digital learning systems become essential. In this regard, the proposed integrated e-module functions as an educational analogue of the digital twin concept, enabling students to internalize industry-relevant processes before entering actual workplaces.

Therefore, this study extends the application of the twin process concept from industrial engineering into vocational pedagogy, demonstrating that interactive e-modules can operationalize the linkage between exogenous industry demands, endogenous instructional design, and the learning process itself. This alignment supports the development of adaptive competencies required for logistics vocational graduates in Industry 4.0 contexts (Jeong & González-Gómez, 2020; Welly et al., 2023).

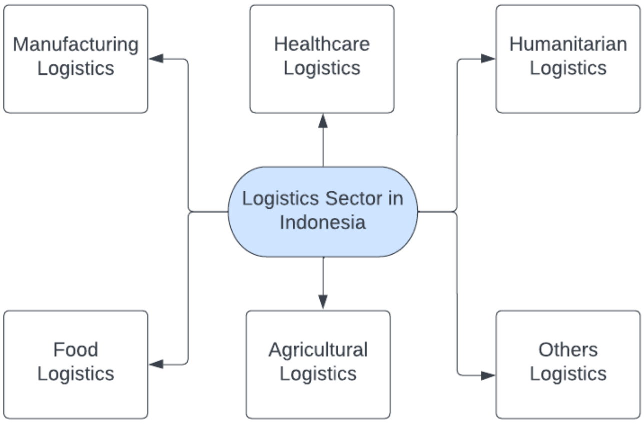

Fig.4 *Logistics sector in Indonesia*

In response to this challenge, the study proposes an integrated e-module designed to accommodate multi-sector logistics contexts as illustrated in Figure 4. This design is grounded in both empirical findings from FGD participants and supporting literature, which highlight the importance of sector-specific, simulation-based, and flexible learning environments (Abdillah & Wahyuilahi, 2025). By integrating cross-sector competencies while maintaining contextual relevance, the e-module reflects a shift toward a more inclusive and holistic curriculum model. Such an approach not only enhances the relevance of learning but also prepares students for diverse career pathways within the logistics ecosystem. This reflects the need for inclusive curriculum design that moves beyond single-sector instruction toward holistic models capable of preparing students for diverse logistics pathways. Moreover, thematic findings were systematically categorized into exogenous factors (industry demands), endogenous factors (curriculum structure and institutional capacity), and learning process dimensions (pedagogical mediation and technology integration) (Nahrowi et al., 2025).

Ultimately, this study makes a key contribution by demonstrating that inventory learning in SMK Logistics Engineering can be transformed through the integration of Guy's framework and the digital twin concept. This transformation moves beyond incremental improvements toward a more systemic reconfiguration of vocational learning. By aligning industry demands, educational structures, and pedagogical processes, the proposed model provides a robust foundation for developing adaptive competencies required in contemporary logistics systems.

4.2 Designing E-Module Inventory Learning

The findings indicate that the design of the e-module must translate industry-driven competencies and pedagogical requirements into concrete learning components. The integration of exogenous demands from the logistics sector with endogenous educational structures necessitates a learning design that is not only technically relevant but also pedagogically adaptive. In response to these findings, the e-module is structured to reflect real operational contexts while accommodating contemporary learning preferences of vocational students, who tend to favor concise, visually rich, and interactive digital content. This approach ensures that learning activities are aligned with authentic industry practices while remaining accessible and engaging for learners. Consequently, the following section elaborates the core content structure of the e-module, which operationalizes the empirical insights and theoretical foundations identified in this study. Content material will be packaged according to the needs of the current generation, who prefer short videos, games, visually appealing content, and concise theory focusing on essential understanding. The elaboration of the e-module content is as follows:

a. Concept and Flow: explains the definition, functions, urgency of inventory, flow of goods movement, and its relationship with the supply chain.
b. Inventory Control Methods: introduces various methods and tools supporting inventory control such as the Economic Order Quantity (EOQ) method, ABC Classification, Material Requirement Planning (MRP), Stock-taking, P model, and Q model.
c. Cost Structure: emphasizes on enhancing students' ability to identify all costs associated with inventory-related activities.
d. Actual Case Studies: enhances adaptive skills by enriching examples both of actual complex and simple problems that often arise in the industry along with several alternative solutions.
e. Related Documents: encourages students to understand the rules and documents associated with inventory planning and control.
f. Reporting Mechanism: focuses on providing an overview of the reporting process when deviations from the plan occur, guided by the applicable industry Standard Operating Procedures (SOP).

Experts in the FGD agreed that the modules in inventory activities need to be adjusted to the six sectors in Figure 5 that adapted by curriculum SMK Logistics Engineering document that active in Indonesia. Learning that combines industry cases with various learning approaches and integrated activities will be able to enhance more integrated learning. Additionally, the use of technology will be able to make learning more interactive and engaging. This is expected to address the need for inventory learning that is interactive, engaging, and integrated. Based on the findings of this study, it is essential to consider that designing an effective e-module in the field of logistics requires a comprehensive and structured approach to ensure that the resulting learning is effective and relevant to the needs of the industry. The following are several aspects that demonstrate the relationship between e-module design and learning effectiveness: relevant curriculum: the e-module must be designed based on a curriculum that is relevant to the needs of the logistics industry (Afinda, B. N., Anwar, S., & Sumarna, O., 2023; Ezz, I. S. A. A. R., 2023). This ensures that the material delivered aligns with the skills and knowledge required in the field. Technology integration: the appropriate use of technology in e-modules, such as logistics simulations, supply chain management software, and data analysis tools, can enhance students' understanding of complex logistics concepts (Miying Yang, Mingtao Fu, Zihan Zhang, 2021). Interactivity and engagement: interactive and engaging e-modules can increase student involvement. Features such as interactive quizzes, demonstration videos, and case studies can make learning more dynamic and help students grasp the material more easily.

Accessibility: E-modules should be easily accessible to all students at any time and place (Eriyanti, I. L., Jumadi, J., Yanarti, Y., & Rosiningtias, W., 2023; Afifah, D.I., Rahayu, E.S., & Anggraito, Y.U, 2018). This allows students to learn at their own pace and review material as needed. Feedback and evaluation: integrated evaluation systems within e-modules, such as online tests and practical assignments, can provide prompt feedback to students on their progress (Carless, D., & Boud, D., 2018). This helps students identify areas that need improvement. Practical application: effective e-modules should include practical applications relevant to the logistics context (Reis, João, 2023). For instance, simulations of inventory management, warehouse operations, and delivery routes can provide important practical experience for students. Collaboration and communication: collaborative features in e-modules, such as discussion forums and group projects, can enhance students' communication and teamwork skills (Miguel Ángel Herrera-Pavo, 2021). This is crucial in the logistics field, which often requires team coordination. Continuous development: e-modules must be continuously updated according to the latest developments in logistics and technology (R. Roy, et.al., 2016). This ensures that learning materials remain relevant and up-to-date. Competency assessment: e-modules should be designed to assess students' competencies comprehensively, including cognitive, affective, and psychomotor aspects. This assessment helps ensure that students truly understand and can apply logistics concepts in real situations. Therefore, this e-module research is highly relevant for preparing competent graduates with a thorough understanding of logistics. The design of the e-module takes into account innovative and communicative learning aspects.

5. Conclusion

The research results indicate that there is a significant need for the development of an integrated inventory e-module to enhance the adaptive skills of vocational school graduates. This e-module can accommodate the understanding of logistics inventory needs for the six core sectors in Indonesia. The content of industry needs should be made more realistic in the form of simulations, job roles, and modules that provide real case scenarios found in the industry. This is expected to enable the design of integrated, interactive, and electronic-based modules that are well-designed, implementable, and adaptive for vocational high school students in logistics technology. This way, students can become skilled, knowledgeable, and understand its application in the industry, especially in inventory activities in the logistics industry. Recommendations for future research include following up on other activities from upstream to downstream in various logistics fields such as healthcare, services, food, and others. Additionally, practical application and development should be implemented in the form of more comprehensive learning.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Author Contribution

Conceptualization, methodology, investigation, data curation, formal analysis, writing – original draft, visualization, project administration, funding acquisition, supervision: *Vina Dwiyanti;* ***investigation, data curation, validation, writing – review & editing:*** *Hanissa Okitasari;* ***conceptualization, supervision, validation, writing – review & editing:*** *Ana A;* ***digital learning media development, visualization, writing – review & editing:*** *Affero Ismail.*

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