Bridging Indonesia's Logistics Skills Gap: A 3D Social-Interdependence Simulator for Collaborative Higher-Order Thinking in Supply Chain Education

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ABSTRACT:

Indonesia's declining Logistics Performance Index highlights a competency gap that requires more interactive and collaborative logistics education. This conceptual paper proposes a 3D Social-Interdependence Simulator for supply-chain learning, grounded in Design Science Research and ADDIE. The simulator combines asymmetric role-play, real-time collaboration, and adaptive learning to support Collaborative Higher-Order Thinking Skills. Its cloud-based Model-View-Controller architecture integrates WebGL/Three.js visualization, WebSocket communication, PostgreSQL–MongoDB data management, and AI-Adaptive Difficulty Adjustment to maintain learners within the Zone of Proximal Development. The paper contributes a conceptual learning model, software architecture, and future validation blueprint. It does not claim classroom trials or empirical effectiveness at this stage.

Keyword: 3D Social-Interdependence Simulator, Collaborative Higher-Order Thinking Skills, Supply Chain Education, Design Science Research, AI-Adaptive Difficulty Adjustment, Logistics Skills Gap

1. Introduction

Indonesia's logistics sector faces a strategic competency gap, reflected in the decline of its Logistics Performance Index ranking from 46th in 2018 to 63rd in 2023 and the weakening of its logistics competence score from 3.1 to 2.9 (World Bank, 2023). This condition signals a mismatch between higher education outcomes and the demands of Industry 4.0 logistics practice (Sirait et al., 2025). As Generation Z learners increasingly need visual, interactive, collaborative, and technology-supported environments, conventional lectures and static case studies are insufficient for developing analytical and collaborative supply-chain decision-making skills (Woschank & Pacher, 2020; Brau et al., 2019; Nylund & Lanz, 2020).

Existing logistics simulations, including Beer Game and ERP-based platforms, often remain linear, costly, static, or limited in representing inter-role social interdependence (Rozhkov et al., 2022; Roser et al., 2021; Wang et al., 2024; Faisal et al., 2023). To address this gap, this paper proposes a 3D Social-Interdependence Simulator for supply-chain education. Positioned as a Software Architecture and Conceptual Framework Paper grounded in Design Science Research, the study contributes a conceptual learning model, system architecture, artifact design rationale, and future validation blueprint, without claiming classroom trials or empirical effectiveness at this stage.

2. Literature Review and Conceptual Basis

The simulator is conceptually grounded in situated learning, experiential learning, Social Interdependence Theory, and Collaborative Higher-Order Thinking Skills (Collaborative HOTS). These perspectives emphasize authentic, experience-based learning through reflection, experimentation, and shared problem solving (Salinas-Navarro et al., 2024; Fawcett et al., 2020). In supply-chain education, simulation enables learners to test decisions safely while experiencing interdependent material, information, and financial flows (Fawcett et al., 2020). By assigning asymmetric roles such as purchasing, production, sales, and finance managers, the proposed simulator is designed to promote analytical, evaluative, and creative decision-making during collaborative responses to disruptions such as demand shocks, delays, and bullwhip effects (Inouye & Kling, 2020; Stefan et al., 2019).

Previous studies show that logistics learning media still rely heavily on traditional computer-based simulations, while immersive, adaptive, and socially interdependent designs remain limited (Sirait et al., 2025; Bikovska, 2019; Hidayatno et al., 2019). Classical simulators tend to simplify supply-chain complexity, whereas ERP-based platforms offer process realism but are often costly and difficult to configure (Rozhkov et al., 2022; Wang et al., 2024). These limitations support the need for a lightweight, browser-based, data-driven 3D simulator that can strengthen collaborative learning in higher education contexts.

3. Methodology

This study adopts Design Science Research (DSR) integrated with the ADDIE instructional design framework. DSR structures the artifact-oriented inquiry, while ADDIE guides the educational design process from analysis to future evaluation (Drechsler & Hevner, 2022). The Relevance Cycle identifies Indonesia’s logistics competency gap and Generation Z learning needs; the Design Cycle translates these needs into simulator features such as asymmetric role-play, gamification, WebGL/Three.js visualization, and AI-Adaptive Difficulty Adjustment (AI-DDA); and the Rigor Cycle anchors the design in theory and future validation criteria. Together, this integration operationalizes key simulation-learning factors, including interactivity, scenario-based cases, data-driven decision-making, collaboration, communication, and hands-on experience. This paper is positioned as a *Software Architecture and Conceptual Framework Paper*. It therefore focuses on artifact conceptualization, architectural specification, theoretical alignment, and a future evaluation blueprint, without reporting classroom trials, user testing, statistical analysis, or measured learning outcomes.

Figure 1. Integrated Hevner Cycle Design Science Research (DSR) Methodology

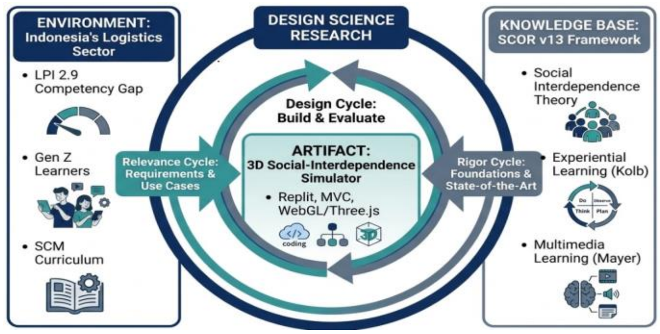


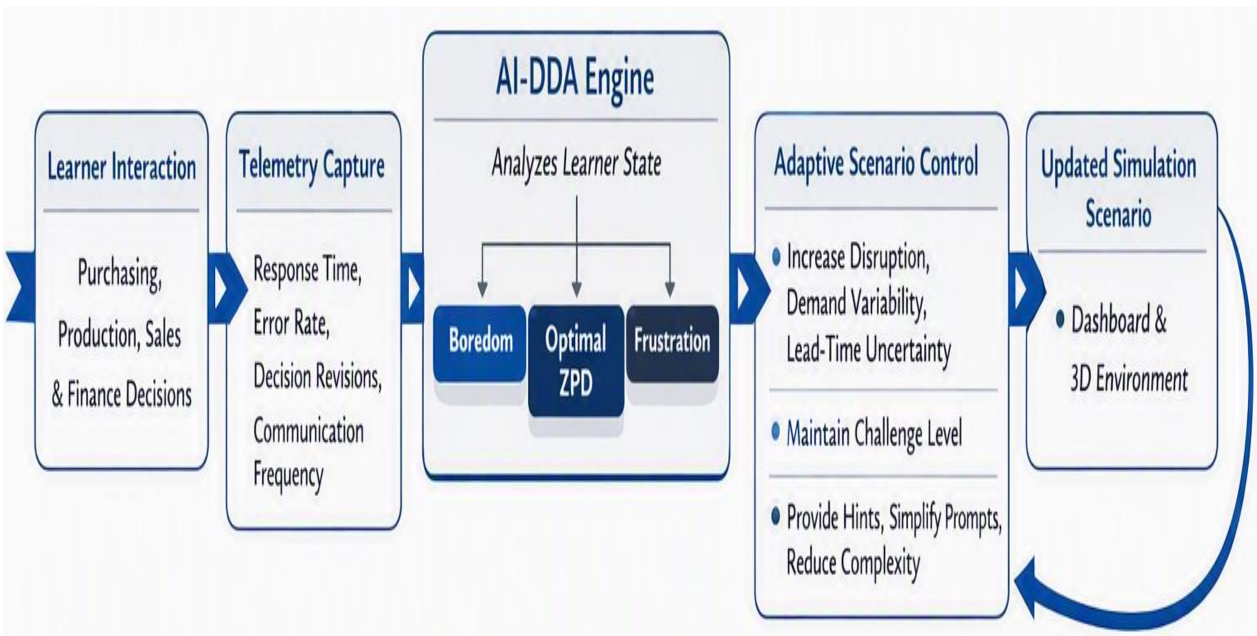
Table 1. ADDIE Framework

Phase	Components	SCM Operations	Indicator
Analysis	Scenario-based case; Data-driven	Map LPI issues, disruption scenarios, costs, capacity, and lead time.	Valid scenarios and parameters.
Design	Role-play; Collaboration; Communication	Design asymmetric roles, team coordination, and real-time communication channels.	Clear roles and high interdependence.
Development	Gamification; Interactive	Encode points, leaderboards, feedback loops, and WebGL/Three.js visualizations.	Expected stable visual-response design.
Implementation	Hands-on Experience	Students are planned to execute tactical decisions in a future virtual lab.	Planned participation and adaptive-strategy indicators.
Evaluation	Multidimensional evaluation	Specify future measurement plan for SCOR KPIs, ROI, SUS, Grit, and cognitive outcomes.	Future validation indicators.

4. System Architecture and Specifications

The simulator uses a cloud-based MVC architecture built on Replit.com, integrating WebGL/Three.js for client-side 3D visualization and WebSocket for real-time multi-role synchronization. Server-side components manage SCOR supply-chain logic and adaptive scenarios, while an AI-DDA engine dynamically adjusts complexity based on learner telemetry (error rates, response times, persistence) to maintain optimal challenge within the Zone of Proximal Development. A polyglot database pairs PostgreSQL for structured SCM transactions with MongoDB for high-volume interaction logs, reflecting broader digital-twin and virtual–real fusion approaches to logistics and smart manufacturing systems (Agalianos et al., 2020; Wang & Luo, 2021). Designed for modularity, scalability, and maintainability, technical implementation, stress testing, and classroom validation are reserved for future work.

Figure 2. AI-Adaptive Difficulty Adjustment Logic Based on Learner Telemetry



5. Operationalization of the Three-Phase Learning Model

The simulator is operationalized through three phases: Preparation, Learning Process, and Evaluation. The Preparation phase aligns content with undergraduate logistics and industrial engineering competencies, including KKNI Level 6 and ABET-oriented outcomes, while specifying pre-tests, learner profiles, and Grit indicators for future validation. The Learning Process phase engages students in asymmetric role-play as purchasing, production, sales, and finance managers, with decisions synchronized by the workflow controller and monitored through telemetry data. The use of role-based negotiation, interactive order-to-delivery learning activities, and cloud-supported learning-factory concepts strengthens the rationale for this collaborative workflow design (Inouye & Kling, 2020; Nylund & Lanz, 2020; Kolesnyk et al., 2021). The Evaluation phase outlines future assessment of logistics KPIs, cognitive outcomes, motivation, engagement, Grit, and usability through instruments such as SUS, consistent with cyber-learning research that links self-regulation, grit, and performance dynamics (Kooken et al., 2021). Overall, the model links curriculum design, simulator operation, and future empirical validation.

Figure 3. Operationalization of the Three-Phase Learning Model

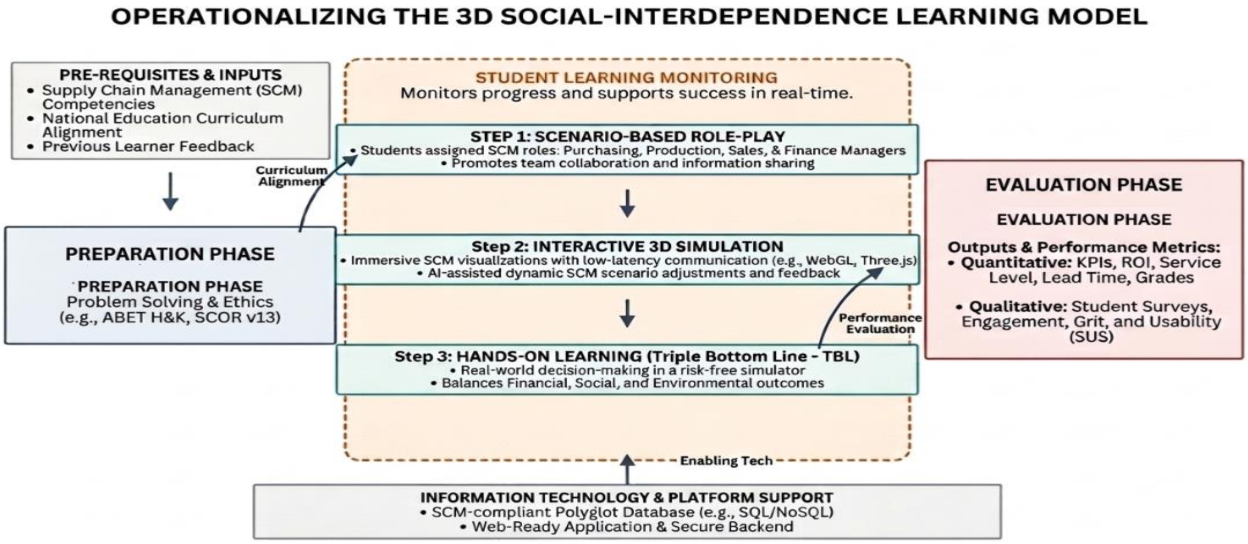


Figure 4. Inventory 3D, Production 3D, Showroom 3D

6. Discussion

The architectural novelty of the proposed simulator lies in the integration of social interdependence, 3D visualization, polyglot data management, and AI-DDA adaptive learning logic. Compared with traditional logistics simulators that rely on static parameters or single-database architectures, the proposed design separates SCM transactions from learner telemetry and links both to adaptive scenario control. This enables the simulator to conceptually support real-time collaboration, role-based decision-making, and cognitive scaffolding, while extending prior work on simulation games, serious games, and gaming-based logistics research methods (Bikovska, 2019; Lukosch & Comes, 2019; Stefan et al., 2019). However, these contributions are design propositions that still require future technical testing, classroom implementation, and empirical validation.

Table 2. Paradigmatic Comparison of Logistics Simulator

Dimensions	Traditional	ERPsim	Proposal
Data Architecture	Spreadsheet/RDBMS tunggal.	RDBMS is centralized and rigid.	PostgreSQL + MongoDB.
Adaptability	Statis/manual.	Parameter tetap.	ZPD-based AI-DDA.
Interface	2D/table of numbers.	SAP complex.	3D Cockpit WebGL.
Accessibility	Local installation/licensing.	Expensive and complicated.	Cloud, browser-ready.
Evaluation	Cognitive final scores.	Partial financial KPIs.	Kognitif, Grit, SUS.

7. Conclusion and Future Directions

This paper proposes a cloud-based 3D Social-Interdependence Simulator to address Indonesia's logistics competency gap through collaborative, adaptive, and visually immersive supply-chain learning. Grounded in Design Science Research, it contributes a conceptual learning model, MVC-based architecture, and future evaluation blueprint integrating asymmetric role-play, WebGL/Three.js, WebSocket synchronization, SCOR logic, PostgreSQL–MongoDB data separation, and AI-DDA support. As a conceptual artifact, it still requires implementation, classroom trials, usability and stress testing, and longitudinal validation of learning outcomes, logistics KPIs, engagement, Grit, and future digital-twin or smart-tutoring potential.

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