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Gamified simulation to improve student comprehension and motivation in transportation systems

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ABSTRACT

This study investigates the effectiveness of a gamified transportation simulation game in improving student comprehension and motivation within a Logistics Engineering course. Employing a pre-experimental pre-test/post-test design, the study involved a sample of 24 undergraduate students. The study collected data using performance penalty scores to measure comprehension and adapted questionnaires to assess motivation. To address methodological rigors, the instrument's reliability was validated (Cronbach's Alpha = 0.881), and the data were analyzed using the robust non-parametric Wilcoxon Signed-Rank Test. The results indicate that the gamified intervention significantly enhanced both students' problem-solving accuracy and their intrinsic motivation to learn complex logistics concepts ($p < 0.001$). The study's primary contribution lies in its methodological novelty: a dynamic penalty scoring system based on the deviation between students' manual calculations and optimal algorithmic solutions, integrated within a scaffolded learning environment. Theoretically, this research reinforces constructivist learning by bridging abstract mathematical formulations with interactive gamification. Practically, it provides an easily deployable educational tool for engineering curricula. However, the study's limitations include a small sample size, the absence of a control group, and potential testing effects. Future implementations should address these gaps further to validate the tool's scalability and long-term impact.

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INTRODUCTION

The ability to manage transportation and distribution systems is a mandatory competency for graduates of the Bachelor's Degree of Logistics Engineering program. This requirement is outlined in the 2024 curriculum guide. According to the curriculum, graduates must possess skills in managing transportation routes and scheduling, as well as understanding key elements related to transportation costs. Based on the exit survey from the bachelor's program, 60.9% of respondents rated the ability to design and improve logistics systems as important, while 39.1% rated it as very important. This emphasis is further supported by alumni feedback, which identified the Transportation Systems course as one of the most relevant in preparing them for professional roles.

However, the Transportation Systems course in the Logistics Engineering bachelor program at the Surabaya Campus is implemented significantly below the standard of similar programs at the main campus. The Logistics Engineering bachelor program in Surabaya also has the lowest student enrollment among all study programs at Telkom University Surabaya Campus. Furthermore, the academic capabilities of incoming students are generally lower compared to those at the main campus. One of the main challenges hindering students' understanding of transportation and distribution systems is their difficulty in grasping the underlying mathematical formulations and algorithms used to solve transportation problems. Typically derived from real-world transportation and distribution scenarios, these formulations can be abstract and difficult to comprehend without sufficient context or visualization. Therefore, educational tools that bridge this gap are essential to support student learning.

While previous studies have utilized simulation-based approaches to teach transportation and distribution concepts, they often lack critical integration of mathematical validation. For instance, Abasian et al.,(2020) and D'Amours & Rönnqvist (2013) developed effective games for supply chain planning and collaborative logistics, respectively, but their focus remained largely on high-level strategic decision-making. Similarly, interactive tools by Gaudron et al., (2019), Fjeld & Hedlinger (2005), Klock et al., (2021), and Kourounioti et al., (2018) successfully visualized urban distribution and transport planning and synchro-modal decision-making, yet they functioned more as descriptive scenarios rather than rigorous algorithmic challenges. Meanwhile, recent developments in digital simulations for vocational and technical education have shown broader promise in enhancing conceptual engagement (Hakim et al., 2022; Rahman et al., 2026; Rahmat et al., 2019; Romero et al., 2017; Tiari et al., 2020). Recent computational research highlights the growing trend of gamifying complex operations research tasks, such as the Vehicle Routing Problem (Kullman et al., 2025). However, translating these advanced concepts into accessible, curriculum-based educational tools remains a challenge.

Furthermore, comprehensive reviews on gamification in education by Koivisto & Hamari (2019), Deterding et al., (2011), and Majuri et al., (2018) reveal a heavy reliance on basic achievements-oriented elements such as points and leaderboards without linking these rewards directly to algorithmic accuracy and mathematical comprehension. A critical research gap remains in combining progressive problem complexity with real-time algorithmic feedback to teach operations research formulations.

This study fills that gap by introducing a conceptual and methodological novelty beyond local implementation context. We developed a gamified simulation featuring a dynamic penalty scoring system based on the exact deviation between a student's manual calculation and the optimal algorithmic solution. This mechanism is combined with instructional scaffolding, gradually increasing problem complexity from the Traveling Salesman Problem (TSP) to the Vehicle Routing Problem with Time Window (VRP-TW). The expected contribution of this research is twofold: theoretically, it provides empirical evidence on how integrating competitive algorithmic feedback within a constructivist framework enhances cognitive retention in STEM education; practically, it offers a validated, interactive learning tool that can be adopted by other engineering programs facing similar challenges in teaching abstract logistics models.

This research concludes that the developed gamified transportation simulation successfully improves both student comprehension and learning motivation when dealing with complex operations research problems. By utilizing a scaffolded level architecture and a dynamic algorithmic penalty scoring mechanism, the educational tool directly answered the study's core objectives: it significantly minimized manual routing errors and drastically elevated students' analytical confidence. The primary practical contribution of this study is the delivery of a validated, lightweight, and easily deployable Microsoft Excel prototype tailored for engineering curricula facing enrollment and resource constraints. Future implementations will scale this tool across larger student cohorts and introduce a control group framework to further validate its long-term learning retention metrics.

METHOD

Research Design

This study employed a quantitative evaluation approach utilizing a pre-experimental, one-group pre-test/post-test design. The primary objective was to assess whether a gamified transportation simulation could enhance students' comprehension and engagement in transportation and distribution systems.

Population and Sample

This study employed a quantitative evaluation approach utilizing a pre-experimental, one-group pre-test/post-test design. The primary objective was to assess whether a gamified transportation simulation could enhance students' comprehension and engagement in transportation and distribution systems. The population comprised undergraduate students enrolled in the Transportation Systems course at the Surabaya campus. The sample consisted of 24 sophomore students (58% female, 42% male) divided into six collaborative groups. None of the participants had prior experience with transportation optimization software. The use of a concise three-week intervention period was deliberately chosen to minimize internal validity threats, such as maturation and history effects.

Instruments and Intervention

Data were gathered using two main instruments: the simulation game (measuring comprehension) and a questionnaire (measuring motivation).

Transportation Simulation Game (Intervention Tool)

The gamified approach progressively increased problem complexity across five classic operations research levels: (1) Traveling Salesman Problem (TSP), (2) Multi-TSP or Vehicle Routing Problem (VRP), (3) Capacitated Vehicle Routing Problem (CVRP), (4) Vehicle Routing with Pickups and deliveries (VRP-PD), and (5) Vehicle Routing with Time Windows (VRP-TW). The game prototype, developed in Microsoft Excel, utilizes a point-based penalty system. The appearance of the game prototype is shown in Figure 1 for the main menu and Figure 2 for the problem interface.

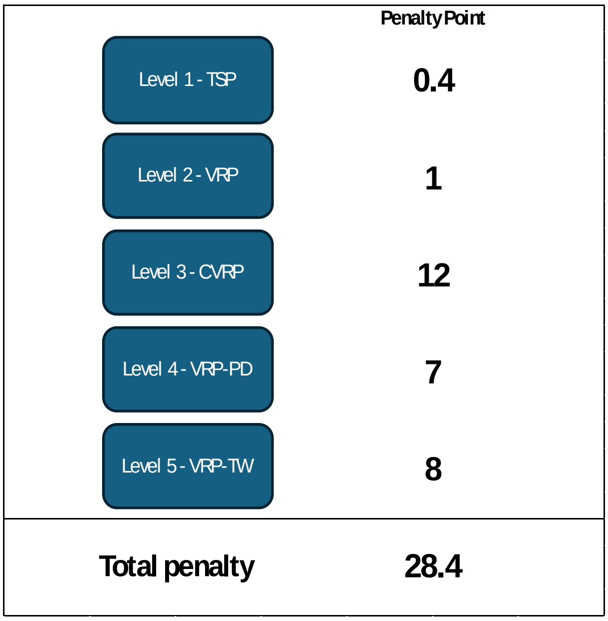

Figure 1. The Main Menu of Transportation Simulation Game

Each level features four primary functionalities: a Randomize Button (to generate coordinates within a 10x10 grid), a Lock Location Button, a Solve Button (activating the optimal algorithm), and a Result Input Field.

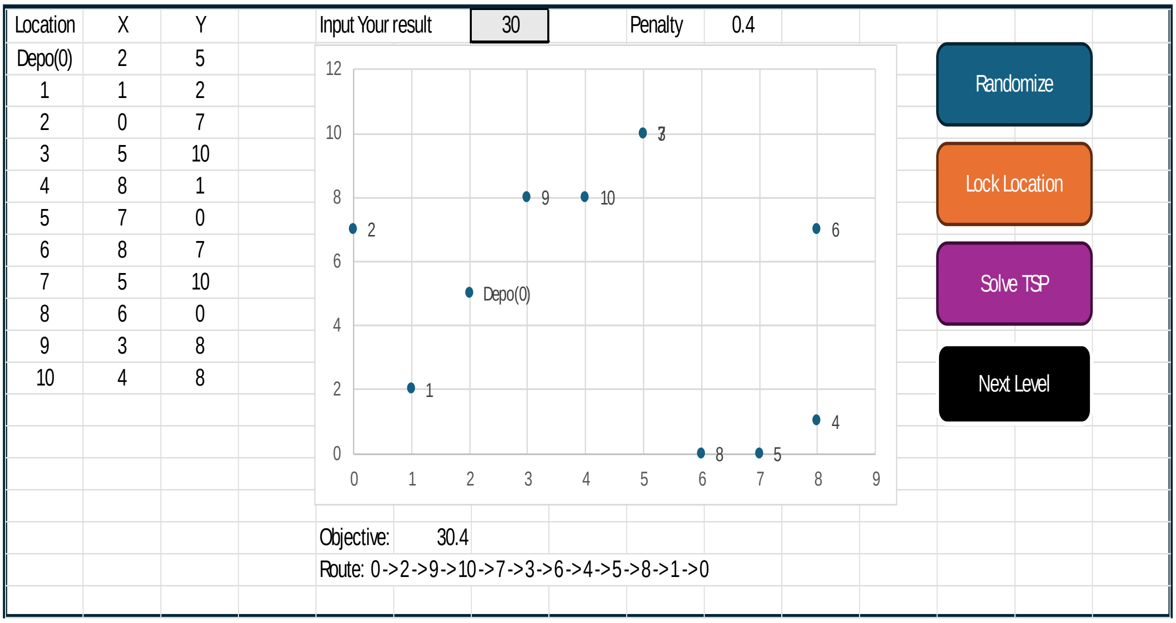

Figure 2. The Interface of Each Level of the Problem

Students are required to input their manually calculated solutions into the system before using the built-in algorithm. The system calculates a penalty score based on how far the manual solution deviates from the optimal algorithmic result. The lower the accumulated penalty points, the better the student's comprehension.

Motivation Questionnaire

Motivation and interest were assessed using a 4-point Likert scale questionnaire adapted from reliable tools in technical education (Daroini et al., 2022; Daroini & Alfiana, 2022), and supported by related instructional module studies (Buulolo, 2025; Sriyunianti et al., 2022; Tasya et al., 2023). To ensure the instrument's trustworthiness for this specific cohort, construct validity and internal consistency were thoroughly evaluated. The reliability test yielded a strong Cronbach's Alpha of 0.881 for the overall questionnaire. Furthermore, Pearson Product-Moment correlations confirmed that the majority of items had significant positive correlations with the total score ($p < 0.05$), establishing robust construct validity.

Data Collection Procedure

To ensure replicability, the data collection was systematically conducted in three distinct phases over three weeks:

1. Week 1 (Pre-test): Students completed the pre-questionnaire to gauge baseline motivation. They then played the simulation using their existing knowledge, and their initial penalty scores were recorded.
2. Week 2 (Intervention): Students received instructional treatment on the correct algorithms to solve the problems, such as the nearest neighbor logic for TSP and the clustering method for VRP.
3. Week 3 (Post-test): Students re-applied the simulation game to obtain their new penalty scores, followed by the post-questionnaire to identify any significant changes in motivation and understanding.

Data Analysis Techniques

The collected data were evaluated to determine significant differences before and after the intervention. To determine the appropriate statistical test, a Shapiro-Wilk normality test was executed first on both the pre-test and post-test scores. The analysis confirmed that the dataset significantly deviated from a normal distribution ($p < 0.05$), meaning the standard assumptions required for parametric statistics were formally violated. Due to this violation, the small sample size (N=24), and the ordinal nature of the questionnaire data, a non-parametric Wilcoxon Signed-Rank Test was employed as the definitive, robust alternative to parametric paired *t*-test frameworks (Field, 2024; Hair et al., 2019). This step-by-step approach ensures that interpretations regarding cognitive gains and motivational increases are mathematically justified and not compromised by zero-variance or normality issues inherent in small datasets.

RESULTS AND DISCUSSION

Results

Prior to evaluating the intervention's impact, the reliability of the adapted questionnaire was tested. The results in Table 1 demonstrate that all questionnaire dimensions possess excellent internal consistency, well above the acceptable threshold of 0.70 established in educational research.

Table 1. Instrument Reliability Results

No.	Dimension / Variable	Number of Items	Cronbach's Alpha	Status
1	Motivation and Interest in Learning	7	0.720	Reliable
2	Understanding of the Material	8	0.737	Reliable
3	Application of Programs in Learning	8	0.804	Reliable
Overall Questionnaire		**23**	**0.881**	**Highly Reliable**

The primary analysis measured differences in both comprehension (Penalty Score) and motivation before and after the gamification intervention. Table 2 presents the descriptive statistics detailing the average scores for each questionnaire item before and after the intervention, illustrating a consistent upward trend in student responses across all indicators.

Table 2. Detailed Items and the Recapitulation Result of the Questionnaire

No.	Categories	Average Before	Average After
Motivation and Interest in Learning			
1	I like the Transportation Systems course.	2.00	3.00
2	I want to become proficient in route planning.	3.00	3.00
3	I enjoy being given real-life examples in the material and problems being studied.	3.00	3.00
4	I enjoy solving problems related to the field of transportation.	2.00	3.00
5	I do not give up easily when faced with difficult problems.	2.00	3.00
6	I actively participate in the learning process.	2.00	3.00
7	I consider this course important and beneficial for my future.	3.00	3.00
Understanding of the Material			
1	I can easily grasp the material being taught.	1.00	2.00
2	I am not afraid of making mistakes when solving problems during the learning process.	2.00	3.00
3	I like being given many opportunities to ask questions about material I do not understand.	2.00	3.00
4	I understand more easily when the lecturer introduces various ways to solve a problem.	2.00	3.00
5	I understand the material more easily when using a problem-solving program.	2.00	3.00
6	I can apply the concepts I've learned in various situations or problems.	2.00	3.00
7	I can identify the correct steps to solve problems.	1.00	2.00
8	I need media, tools, and learning facilities to improve my understanding of the material.	2.00	3.00
Application of Programs in Learning			
1	I use programs to solve problems that are difficult to handle manually.	2.00	3.00

No.	Categories	Average Before	Average After
2	I understand problems more easily using transportation simulation programs.	2.00	3.00
3	My understanding improves when I use the program.	2.00	2.00
4	I feel more motivated to learn when I use a program to solve problems.	2.00	3.00
5	Using the program supports me in thinking logically.	2.00	3.00
6	The program is very helpful for me in solving problems.	2.00	3.00
7	Using the program improves my problem-solving ability.	2.00	3.00
8	The program helps me analyze problems.	2.00	3.00

To determine the statistical significance of these improvements, a Wilcoxon Signed-Rank Test was conducted. Table 3 presents the consolidated inferential results. The analysis reveals a statistically significant improvement in students' conceptual comprehension, evidenced by a dramatic reduction in mean penalty scores from 17.88 to 10.53 ($p < 0.001$). Similarly, the overall motivation questionnaire scores demonstrated a highly significant increase across all assessed dimensions.

Table 3. Wilcoxon Signed-Rank Test Results

No.	Tested Category	Mean Before	Mean After	Wilcoxon Stat (W)	P-Value	Statistical Significance
1	Penalty Score (Comprehension Metric)	17.88	10.53	0.0	< 0.001	Highly Significant (Error reduction)
2	Category 1: Motivation & Interest	16.17	23.04	0.0	< 0.001	Highly Significant (Increase)
3	Category 2: Material Understanding	17.08	25.08	0.0	< 0.001	Highly Significant (Increase)
4	Category 3: Program Application	17.08	25.04	0.0	< 0.001	Highly Significant (Increase)

Discussion

The findings robustly support the hypothesis that integrating a gamified simulation significantly enhances both student comprehension and learning motivation in transportation systems. Rather than relying on the rote memorization of formulas, students who engaged with the simulation exhibited a deeper cognitive grasp of the material.

A critical factor contributing to this outcome is the system's architecture, specifically the dynamic penalty scoring mechanism. By immediately calculating and displaying the deviation between the students' manual calculations and the optimal algorithmic solutions, the game provides real-time, objective feedback. This forces students to actively iterate and critically evaluate their routing decisions, mimicking the mechanics of metaheuristic optimization algorithms. This aligns with recent advancements in educational technology, which emphasize that interactive digital games should transition towards fostering computational thinking and algorithmic problem-solving rather than mere visual engagement (Anggraini et al., 2025).

Furthermore, the interactive mapping of information and instructional scaffolding. Progressing incrementally from basic Traveling Salesman Problem (TSP) to Capacitated Vehicle Routing Problem (CVRP) ensured that students were not cognitively overwhelmed. When compared to previous studies that largely functioned as descriptive scenarios without demanding rigid mathematical validation, our gamified simulation embeds strict algorithmic verification within the user interface. This ensures students do not merely understand the overarching concept of logistics, but also master the mathematical efficiency and accuracy behind it.

This structural success and the resulting error reduction can be deeply understood through multiple interconnected theoretical lenses. First, the incremental progression from basic routing up to complex constraints maps directly onto Csikszentmihalyi (1990)'s Flow Theory. By structuring the simulation into distinct, ascending operations research levels, the game ensured that problem difficulty scaled symmetrically with the students' growing analytical skills. This careful balancing act kept participants within their optimal cognitive "flow channel," effectively mitigating the academic anxiety or boredom often triggered by abstract logistics models.

Second, the iterative behavior driven by real-time feedback aligns heavily with Kolb (2014) Experiential Learning Theory. The simulation interface inherently guides students through a complete experiential loop: they execute a manual routing choice (concrete experience), observe their error deviations immediately (reflective observation), decipher the underlying algorithmic logic by looking at the optimal solution path (abstract conceptualization), and instantly apply their refined strategy to the next randomized problem coordinate set (active experimentation). This continuous cognitive cycle directly accounts for the dramatic reduction in mean penalty scores from 17.88 down to 10.53 ($p < 0.001$).

Furthermore, the sharp post-intervention uptick observed across all motivational dimensions strongly reinforces the core tenets of Self-Determination Theory (Deci & Ryan, 2000) and Constructivist Learning Theory (Piaget, 1952; Vygotsky & Cole, 1978). The simulation's open grid interface granted students a high level of autonomy, while the immediate localized penalty calculations provided objective competence feedback. This combination created the ideal psychological conditions to transform a standard classroom task into an engaging, self-directed learning experience. By measuring these specific shifts in knowledge acquisition and learner engagement, this study successfully fulfills the baseline parameters of Kirkpatrick (1996)'s Evaluation Principles, confirming that gamifying complex operations research tasks yields both measurable cognitive and affective gains.

Despite the positive results, this study acknowledges several methodological limitations that should be considered explicitly in interpreting the findings. First, the absence of a control group makes it challenging to entirely isolate the game's effect from standard instructional maturation over the three-week period. Second, the sample size was relatively small (N=24) and limited to a single cohort, which may restrict the broader generalizability of the findings across different demographics. Third, there is a potential internal validity threat regarding the testing effect; students' growing familiarity with the game's interface by the third week might have contributed slightly to their improved performance, independent of their actual grasp of the routing algorithms. Future implementations should address these limitations by incorporating control groups and expanding the participant cohort.

CONCLUSION

This research concludes that a gamified transportation simulation, characterized by scaffolded complexity and dynamic algorithmic penalty scoring, significantly improves both student comprehension and motivation in learning complex logistics routing problems. Theoretically, the study extends constructivist learning by demonstrating how competitive, real-time algorithmic feedback can solidify abstract mathematical understanding. Practically, it provides educators with a validated, interactive tool to boost student engagement in technical engineering courses. Future research should address current limitations by utilizing larger sample sizes, incorporating control groups, and employing rigorous statistical assumption testing or non-parametric methods to strengthen empirical validity.

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