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Multi-location Scenario-based Serious Game in a Virtual Ship Environment for Enhancing Electrical Troubleshooting Learning Process of Marine Electrical Engineers

Rona Riantini[1], Mochamad Hariadi[1], Supeno Mardi Susiki Nugroho[1], Diah Puspito Wulandari[2], Naufaldi Rahmatullah Dwihartantyo[2]

[1]Department of Electrical Engineering, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia
[2]Department of Computer Engineering, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia

Abstract

One critical human factor that can jeopardize ship safety is failing to address known problems. Troubleshooting abilities are crucial for marine electrical engineers and electro-technical teams, yet this ability is typically developed gradually through field experience. Recent technology provides significant opportunities for creating advanced educational media in maritime education, such as full mission simulators for navigational training. However, its application in electrical troubleshooting remains limited. Serious games allow students to gain experience in troubleshooting without concern for safety or system damage, while also offering flexibility and accessibility from any location. This article proposes a representation of real-world troubleshooting involving multiple locations through a serious game simulator. The presented design framework facilitates clear communication between educators, experts, and game developers, especially for structured multi-location scenarios. As proof of work, an earth fault troubleshooting game was developed using Unreal Engine 5 and tested on 40 marine electrical engineering students, significantly improving test scores (t-statistic: 2.242; p-value: 0.031). In addition, the most significant impact is interest in further learning, scoring 4.4 out of 5, reflecting increased knowledge and confidence. These results underscore the potential of serious games for marine electrical engineering and broader maritime education and training applications.

Keywords: Marine electrical, Serious game, Troubleshooting simulator

1. Introduction

Failure to address an engineering issue aboard a vessel may result in a safety-threatening situation. The Safety and Shipping Review 2024 indicates that the majority of global accidents are attributed to mechanical damage or failure (11,506), followed by collisions with other vessels (3,014), wrecks or strandings (2,808), and contact with port infrastructure (1,916) [1]. The onboard officer and onshore engineer must ensure all issues are resolved before or during the voyage. Failure to Correct Known Problems is categorized under the Human Factor Analysis and Classification System for Maritime Accidents (HFCAS-MA) [2]. Therefore, troubleshooting is indispensable element of every engineering practice. This competence involves identifying and correcting problems in an engineering system by developing a strategy within a time-limited setting [3]. In addition, the increase in automation and digitalization on-board merchant ships changed the operational profiles of the seafarers and their competence requirements for various functions [1,4]. Marine electrical engineers in the shipbuilding company or dockyard must ensure that all the systems function properly. Also, an essential performance requirement of the Electro Technical Officer (ETO) qualification is the ability to detect electrical malfunctions, identify the fault location, and implement measures to prevent damage [5].

Acquiring troubleshooting skills is typically achieved through experiential learning, marked by trial-and-error, on-the-job training, and the progress of problem-solving abilities.

Address for Correspondence: Mochamad Hariadi, Department of Electrical Engineering, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia
E-mail: mochar@its.ac.id
ORCID iD: orcid.org/0000-0002-2194-169X

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Experiential learning was highly effective and provided students with a reflective, collaborative, and hands-on learning experience [6]. Nevertheless, the troubleshooting learning approach is not typically incorporated into a well-organized educational curriculum. The effectiveness of this approach is limited, and it contributes minimally to the development of self-confidence [7]. Structured troubleshooting can be a time-consuming and demanding undertaking. The research by [8] which proposes an approach that leads to more hands-on and job-oriented training reveals that technicians educated in structured troubleshooting resolve twice as many issues in half the time as those taught in traditional methods [2].

Fortunately, recent technological developments offer new innovations for Maritime Education and Training (MET) [4], and additionally, the pandemic situation is forcing the adoption of distance education in the maritime field [3,9]. Over the years, maritime simulators have evolved in various forms depending on their functionality, scale, and purpose [10]. A bibliometric analysis of the digitalization of maritime education [11] demonstrates that the deck department students were the primary beneficiaries of the majority of the publications. The engine department was the subject of only 16 of the 133 studies. Furthermore, 51 of the 133 studies examined the usage of simulators in MET, with a particular emphasis on full-mission bridge simulators. Conversely, there is a substantial lack of research on serious games and game-based learning opportunities in marine electrical troubleshooting, particularly in multi-location fault diagnosis scenarios. While some serious games exist for maritime training, they mainly focus on leadership, navigation, or ship manoeuvring, leaving a significant gap in electrical troubleshooting training for marine engineers. Serious games possess an extraordinary capacity to cultivate future competencies within the 21st-century educational ecosystem [12]. Serious games have the potential to enhance student engagement, motivation, learning methodologies, and cognitive abilities. The primary benefits of serious games is enjoyment, which is accompanied by increased contentment, satisfaction, and a positive mindset [4,13].

Therefore, this article proposes the development of a serious game that focuses specifically on multi-location troubleshooting in marine electrical systems. This research also introduces a framework for designing structured troubleshooting scenarios, facilitating better communication between educators, experts, and game developers. The serious game may be hosted on the cloud, available on a desktop, or designed for mobile platforms. Full mission simulators are very effective in training, while cloud-based simulators provide a cost-effective and easy-to-use remote alternative, and desktop-based simulators are suitable for economic scenarios [5,10]. These simulators also enable large-scale distributed learning modes, which can introduce new training and assessment practices in MET and promote broad access and quality education [14]. In addition, the use of games allows students to learn from their mistakes without worrying about causing problems that could compromise the system or endanger human safety. Another advantage of this learning medium is its flexibility, because it can be accessed anywhere [6,15]. Unlike existing maritime simulators, this approach integrates multi-location troubleshooting ensuring that students experience realistic fault detection processes that require movement between different locations on board a virtual ship. Additionally, the virtual ship environment will offer a comprehensive troubleshooting experience that resembles real-world scenarios. This approach enhances spatial awareness, understanding of system connectivity, and decision-making skills, which are essential for real-world marine electrical engineers.

This paper contributes to the advancement of serious game-based training in marine engineering education by introducing a multi-location troubleshooting simulator designed to enhance the diagnosis of low-insulation (earth fault) issues. Unlike conventional troubleshooting training, which primarily relies on verbal explanations or hands-on field practice where fault conditions cannot be systematically provided as part of training, this approach offers a structured, interactive simulation within a virtual ship environment. The proposed framework facilitates the conversion of expert-designed fault scenarios into immersive gameplay, ensuring that complex troubleshooting processes, particularly those requiring spatial mobility, are accurately represented. This structured design reduces misinterpretation risks, streamlines game development, and provides a more engaging and scalable learning experience for marine electrical engineers.

2. Related Work

Serious games are principally designed to enhance learning and facilitate skills training [16]. Researchers, including Imligiten and Petko [17] conducted a literature review and found that learning through serious games consistently enhances both enjoyment and profound thinking. Furthermore, Imligiten and Petko [17] compared serious games with educational simulations and observed that students using serious games reported deeper levels of thinking, while levels of enjoyment remained comparable between the two groups.

Simulators have been employed for training and certification in MET since the 1950s [18]. Ship bridge simulator-based training practice is well established, and the studies are extensive and still ongoing [19,20]. The role of simulators in maritime training has further evolved with the adoption of immersive and non-immersive technologies to enhance experiential learning. A systematic literature review by

Dewan et al. [15] highlights the increasing integration of simulators for training seafarers in ship maneuverability, collision avoidance, and shipboard safety. Beyond common ship simulators, serious games are gaining traction in maritime education. Gurbuz and Celik [21] studied the effectiveness of the Maritime Leaders at Sea (ML@S) serious game, finding a strong correlation between participation and improved leadership and teamwork skills. By integrating real-world challenges into a game-based environment, ML@S enhances skill development. Additionally, advanced naval simulators support complex multi-vessel scenarios. Sayed et al. [22] present NavySim, a Unity-based tool integrating Hidden Markov Models for intent recognition and threat assessment, which includes vulnerability heatmaps and Closest Point of Approach analysis and aids training and decision-making [7].

In the field of electrical education, virtual laboratories and games have also been developed. Some of them are associated with electrical devices [23], electrical materials [24], electrical circuits [25] and transformator [26]. There are also several studies on ship electrical simulators [27-29]. Research by D'Agostino et al. [30] describes the construction of a multiphysics simulation framework capable of simulating the behaviour of a DC electric ship with electric propulsion, spinning generators, and battery energy storage devices. Tarnapowicz [27] developed a virtual reality power plant simulator for ships, aiming to familiarize users with Power Management System operations.

However, despite the increasing adoption of maritime training simulators, there remains a substantial gap in research focusing on structured, scenario-based troubleshooting within ship electrical systems. Most maritime simulators emphasize navigation, crisis management, or leadership training, whereas electrical troubleshooting is either underexplored or lacks interactivity and gamification. Existing ship electrical simulators typically focus on isolated components rather than offering a multi-location fault diagnosis system that replicates real-world troubleshooting workflows. This study addresses this gap by introducing a serious game-based troubleshooting simulator that integrates multi-location fault diagnosis within a virtual ship environment. Unlike prior studies that emphasize single-location fault simulations, our approach requires players to navigate different ship areas to diagnose and resolve faults dynamically. In addition, regarding earth faults, there is no simulator available for either land-based, or onboard vessels.

3. Materials and Methods

Figure 1 depicts the methodological framework for the development of a multi-location troubleshooting simulator. It illustrates the key components involved, including preliminary design, level design, spatial mapping, scenario structuring, and swim lane diagram development, ensuring a structured and systematic approach to serious game-based troubleshooting training processes. A general framework of a scenario plan, based on the preliminary design, which is specially created for a multi-location context, is proposed for serious game utilization in maritime education. This framework, specially created for a multi-location context, aims to connect the expert or lecturer concept with the game developer to detail the scenario in game development. The proposed framework initiates with the identification of the level design, the specification of distinct areas and locations, and the modular systems employed in each place. This essential information underpins the game design by guaranteeing a comprehensive understanding of each technical component and operational context. Then, the scenario is depicted in a swim lane diagram, which delineates the flow of actions according to location, sequence of stages, roles, and system participation. The modular design and representation of this swim lane diagram enhance the translation of requirements from trainers,

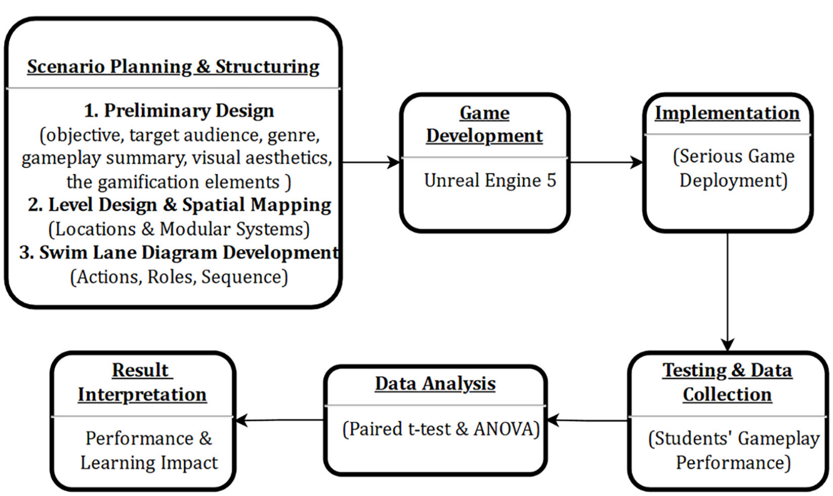


Figure 1. *Methodological framework*

lecturers, or specialists to game developers, as each phase of the troubleshooting process is organized systematically and thoroughly. Consequently, game developers may more readily comprehend the gameplay and foresee critical components to incorporate, thereby diminishing the likelihood of misinterpretation. The framework also organizes games into stages based on difficulty levels, thereby offering an effective learning experience according to the participants' ability levels.

Unreal Engine 5 was selected as the game engine for development. In terms of platform deployment, both Unity and Unreal are top choices; however, for visuals and animation quality, Unreal and CryEngine excel [31]. Additionally, its Blueprint Visual Scripting feature allows for rapid prototyping and scenario adjustments without requiring extensive coding, facilitating game development by non-programmers [32]. The game was developed through several stages: first, designing the ship environment using Unreal Engine Marketplace assets and Blender-modified models; second, implementing game logic with Blueprint scripting, including fault detection, breaker interaction, and insulation measurement; and third, developing the user interface using Unreal Motion Graphics to provide real-time player feedback.

This study included participants from the second year of the marine electrical engineering program to evaluate the game. This assessment seeks to determine the game's effectiveness in enhancing players' understanding and management of earth fault issues, as well as gauge player involvement and responses to the game. Scores and times were recorded throughout gameplay and subsequently analyzed to assess the players' progress and effectiveness in addressing scenario difficulties. Every participant will participate in gameplay three times to evaluate performance enhancement. Various statistical techniques were utilized to evaluate the gaming intervention and investigate performance disparities.

A Paired Samples t-test was implemented to evaluate the intervention's impact on knowledge and perceived troubleshooting abilities with respect to pre and post-test data. The Paired Samples t-test was selected because it is specifically designed for within-subject comparisons [8], making it suitable for evaluating changes in participants' knowledge before and after engaging with the serious game. The test was conducted using the Equation (1) [33]:

$$t = \frac{\bar{X}_d}{S_d/\sqrt{n}} \quad (1)$$

Where:

$\bar{X}_d$ = Mean difference between pre-test and post-test scores.

S_d = Standard deviation of the differences.

n = Number of participants.

The direction of the t-statistic (positive or negative) indicates whether there is an increase or decrease in the measured variable after the intervention. The p-value obtained from the t-test indicates the probability that the observed difference occurred by chance. A p-value below 0.05 indicates rejection of the null hypothesis, confirming that the serious game intervention had a meaningful impact on troubleshooting knowledge. Assumptions for this Paired Samples t-test are that the sample is randomly drawn from the target population.

To analyze the potential effect of prior gaming experience on participants' performance, a One-Way Analysis of Variance (ANOVA) was conducted. ANOVA is used to determine whether there are statistically significant differences between three or more independent groups. It calculates an F-value, which represents the ratio of variance between groups to variance within groups, using the Equation (2):

$$F = \frac{Between\text{-}group\ variance}{Within\text{-}group\ variance} = \frac{\sum n_k (\bar{X}_k - \bar{X})^2/(K-1)}{\sum (X_{ik} - \bar{X}_k)^2/(N-K)} \quad (2)$$

Where:

$\bar{X}_k$ = Mean score of group k.

$\overline{sys}$ = Overall mean.

n_k = Number of observations in group k.

K = Number of groups.

N = Total number of observations.

If the p-value associated with the F-statistic is below 0.05, it suggests that at least one group differs significantly from the others. The assumption of this test is the homogeneity of variance, meaning that variance is equal across all groups.

In addition to these objective performance metrics, participants' perceived engagement and learning impacts were assessed using a self-reported Likert-scale questionnaire (1= strongly disagree to 5= strongly agree), designed to evaluate their interest, motivation, and the perceived effectiveness of the serious game in improving troubleshooting skills.

4. Design and Implementation

The preliminary design covers the game's overall strategy, including its primary objective, target audience, genre, gameplay summary, visual aesthetics, and gamification elements. The preliminary design of the serious game discussed in this article is founded on the work of Riantini [34], which elaborates on a novel approach that engages users and experts in the initial stages of designing a serious game for troubleshooting electrical earth faults in ships. The preliminary design of this serious game aims to deliver a simulation-based learning medium in a virtual environment that enhances students' competencies in solving ship earth faults. Targeted at Marine Electrical Engineering students and ETO trainees, the game is designed as a single-player simulation where users troubleshoot earth faults using tools such as a low-level insulation meter or a high-resistance insulation tester. Players must isolate faults by disconnecting specific loads while monitoring indicators. Success is achieved when fault indications normalize. The immersive visual environment places players in locations like the Ship Engine Control Room or other electrical rooms, supported by navigational aids such as a general arrangement map. Gamification elements include scoring, leaderboards, and completion indicators, alongside a tiered level system that consists of basic (one panel), intermediate (two panels), and advanced (risk of ship blackout) levels. Players earn badges for completing scenarios, incentivizing engagement and skill mastery.

The next phase in the design process involved a comprehensive identification of the site, modular systems, and scenario flow. In the virtual ship environment, different decks and relevant rooms were identified and incorporated into the troubleshooting scenario. As shown in Figure 2, these rooms serve as column titles in the swim lane diagram, providing a clear representation of location transitions within the scenario. This swim lane diagram serves as a comprehensive representation of the interconnections between levels, scenarios, locations, rooms, and modular systems, ensuring a structured and intuitive approach to multi-location troubleshooting training.

Figure 2 presents the swim lane diagram designed to enhance the efficiency of game development by visually mapping the workflow and sequence of events in each scenario. This diagram facilitates effective communication between game developers and maritime engineering trainers/experts, ensuring that each scenario aligns with educational and training objectives. It also illustrates the location transfer flow and the modular systems used at each site, offering a structured representation of troubleshooting activities across different levels.

The installed modular systems train users to analyze faults under different conditions, enhancing their troubleshooting decision-making process. In this study, Modular System 1 consists of an electrical panel equipped with meters and ground fault indicators, requiring users to identify faults by reading meter values and toggling the circuit breaker. Modular System 2, which is not yet fully developed in this study, is designed to require fault analysis using virtual measuring tools instead of built-in meters. The finalized version of the game focuses on Modular System 1, ensuring structured training through real-time troubleshooting exercises based on direct meter readings.

The tutorial level introduces users to the fault-locating process, starting in the wing section of the bridge deck, before moving to the Nav Com room to address the issue. Level 1 maintains a similar level of complexity, focusing on a single panel using Modular System 1, but introduces variability through different circuit breaker pathways (Modular 1-a, 1-b, and 1-c). At Levels 2 and 3, the complexity increases as players must troubleshoot across multiple locations, reinforcing the need for systematic fault diagnosis.

The Unreal Engine is used to construct the troubleshooting simulator, which serves as the primary platform for implementing the fault-finding and diagnostic scenarios.

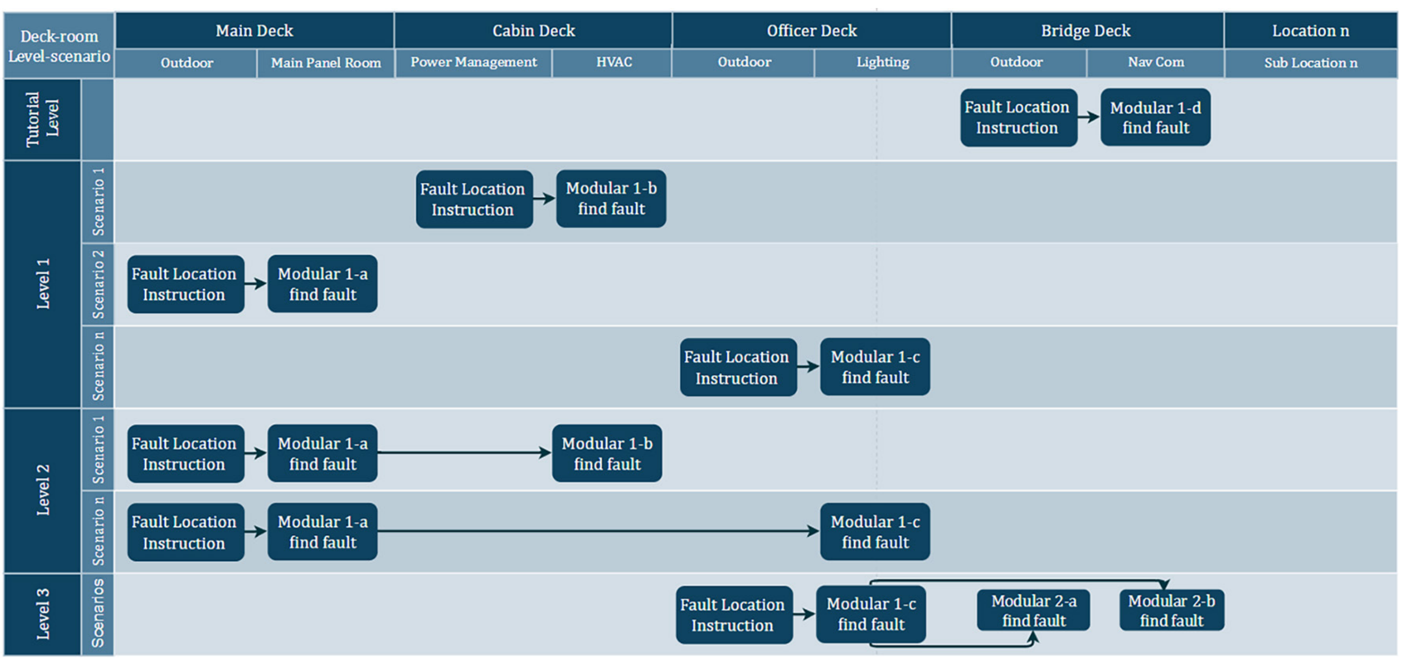


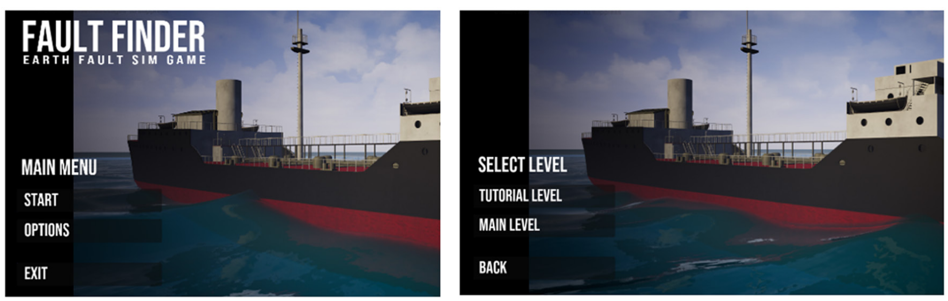
Figure 2. *Swimlane diagram of scenario plan*

The user is presented with a main menu (Figure 3a), then is presented with the option of choosing tutorial level and main level (Figure 3b), which outlines the objectives and procedures for troubleshooting the game.

The in-game heads-up display, depicted in Figure 4, provides the user with instructions, time display, score display (Figure 4a), and control guidance (Figure 4b). The player is presented with the initial objective to access the designated room at the tutorial level. When the "X" icon is pressed, the control guide will be displayed. A tutorial widget will be displayed on the screen at that moment, providing instructions on how to use the keyboard for navigation and interaction in the game. This control guide describes the functions of critical controls, including the button that initiates movement and the button that opens and changes the map or general arrangement selection. This widget is intended to facilitate a more seamless gaming experience, particularly for novice players, by providing them with a clear understanding of how to manage their character or tool. This widget can also be accessed at any point during the game to offer contextual guidance if the player requires assistance.

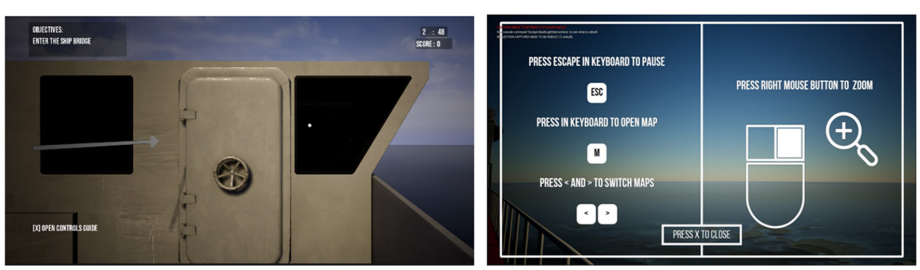
The user is required to attain the target location as depicted in Figures 5 to 8. The user will be required to access different locations to complete scenarios, depending on the scenario plan. If the game is designed for a specific ship, this will also provide the user with experience and ship familiarity.

After reaching the location requested by the game, the user will find a pre-defined modular system, such as Modular System 1, which consists of a panel with circuit breakers, meters, and fault indicators. In this instance, Modular System 1-a, a part of Modular System 1, is situated on the main deck, as illustrated in Figure 6. This modular system can be replicated in all other areas that have been determined with different circuit breaker variables. In Modular System 1, the user must toggle the appropriate circuit breaker until the fault location is identified in order to restore the meter indicator



(a) (b)

Figure 3. *Main menu*



(a) (b)

Figure 4. *In-game heads-up display*

Figure 5. *Target location 1-main deck*

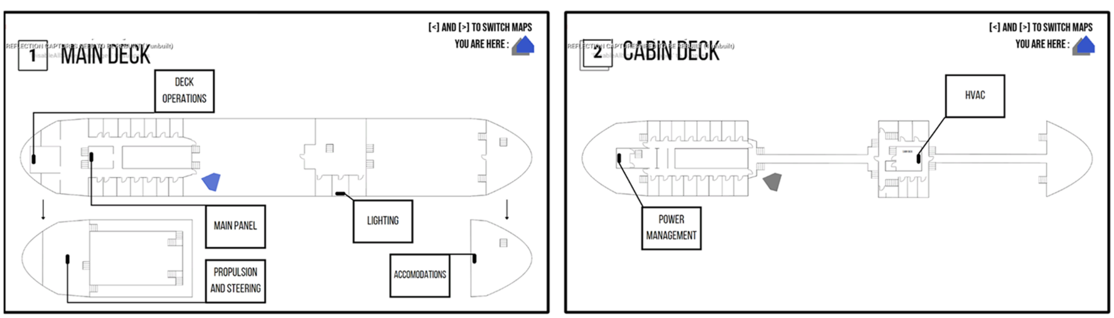
to its normal state. At level 2, the user must proceed to the panel associated with the faulty sources upon identifying a faulty feeder to ascertain the end point of the faulty item.

The user uses the map widget guide depicted in Figure 7 to go toward the subsequent target and fulfill the scenario outlined in the game. For instance, upon identifying a problematic route in the navigation communication system, the user is required to go from the main deck to the bridge deck. The map widget features a user location indicator represented by a blue triangle symbol on the deck map. Figure 7 shows that the user is located in the main deck area. On other decks, the user's position icon will be faintly discernible, signifying that the user is not present on that deck, as illustrated in Figure 7b. The map widget will facilitate access to locating the subsequent target. Upon reaching the designated place, such as the nav-com room, the user can promptly address the issue within the modular system 1-d as illustrated in Figure 8. If the user identifies problems with a certain circuit breaker, it signifies that an endpoint fault has been detected and indicates the user has fulfilled the required objective.

In this study, troubleshooting is still focused on discovering faults or determining which end point is damaged. The modular system can be further extended to cover numerous troubleshooting procedures. This type of multi-location scenario is thought to simulate a real-world troubleshooting experience that a marine engineer would encounter. To ascertain the efficacy of the developed game, testing was conducted on several participants.

5. Evaluation Result and Discussion

The findings of a review paper by [35] indicate that the majority of existing studies on immersive simulated learning environments concentrate on development aspects, including coding, software, and usability, and that there is a dearth of formal, quantitative evaluations of their efficacy. Therefore, the testing and analysis of this study not only measured usability, but also focused on the improvement of the users' learning. The participants consist of 40 third-semester students from the marine electrical studies program who possess foundational electrical knowledge.



(a) (b)

Figure 6. *Modular system 1-a*

Figure 7. *Map widget*

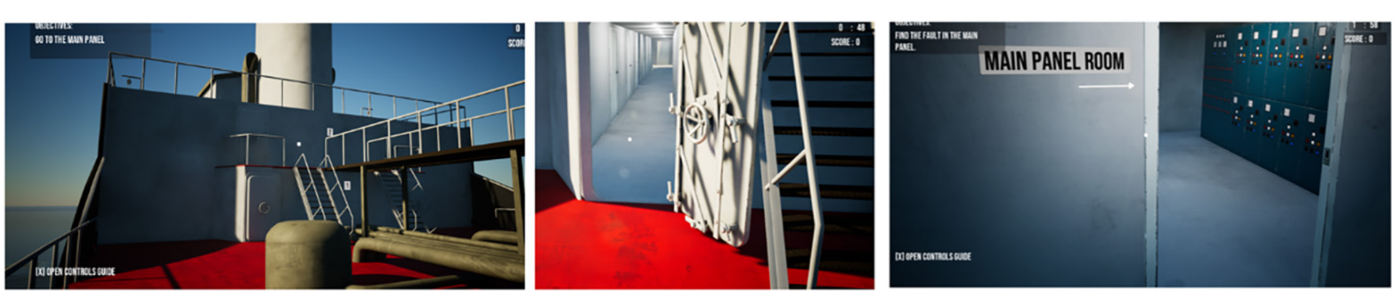


Figure 8. *Target location 2-bridge deck*

Before attempting the game, the respondent completed a questionnaire concerning their background, perceived knowledge, troubleshooting confidence, and a series of knowledge questions. Upon completing the tutorial level, each participant is given three attempts on a subsequent level. The completion time and score of each gameplay session are documented. Then, respondents completed the post-questionnaire, which enquired about their perceived knowledge, troubleshooting confidence, the same knowledge questions given in the pre-test, and their opinions on perceived engagement and learning impact.

Figure 9 depicts the comparison between the total pre-test score and total post-test score, specifically reflecting participants' knowledge improvement. The test assessed participants' understanding of earth fault troubleshooting, including common causes of earth faults, key indicators of low insulation conditions, and the appropriate initial actions to take when an earth fault is detected. In general, the post-test results indicate an increase in overall performance, while some respondents experienced a decrease in individual scores. A paired t-test was conducted to determine the significance of this change, ensuring that the game had a positive impact on participants' knowledge of earth fault troubleshooting.

The paired t-test results show a t-statistic of -2.242, indicating the difference between the pre-test and post-test means is relative to the standard error. The negative t-value signifies that post-test scores were higher than pre-test scores, suggesting an improvement in performance. The p-value of 0.031, which is below the 0.05 significance threshold, indicates that the difference is statistically significant, leading to the rejection of the null hypothesis. This confirms that the intervention had a measurable impact on participants' troubleshooting abilities at the 5% significance level. Although test scores showed an overall increase, certain limitations remain, including a decrease in knowledge among some participants. This decline may be attributed to students guessing answers during the pre-test and post-test rather than demonstrating genuine understanding. In addition, hardware-based training alone is insufficient for developing a deep understanding of system operations. Verbal or written explanations are essential to convey fundamental principles before the practical use of training hardware. This aligns with [36], which emphasizes that combining theoretical instruction with hands-on training enhances learning outcomes (Figure 10).

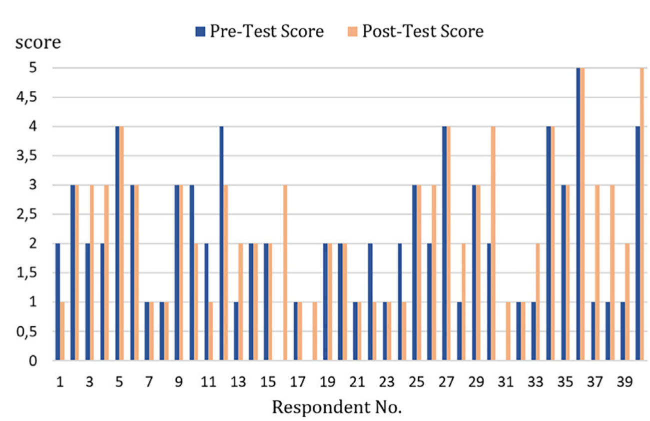


Figure 9. Comparison of pre-test and post-test scores

As the player's progress in solving the troubleshooting scenario is observed, the game score increases, and the decrease in game completion time is recorded. This value is determined by the performance of three games at the same level. Although the scenarios were generated randomly, they were at the same level. Consequently, the problematic circuit breaker may not be intended for or match the designated area. Figure 11 illustrates the score improvement from trial 1 to trial 3. The figure indicates that the number of users

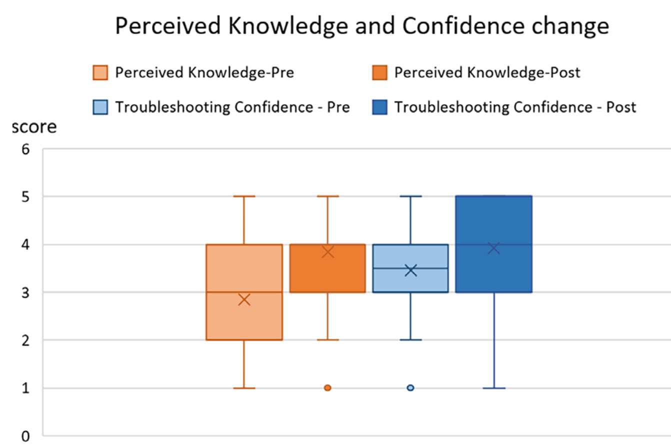


Figure 10. *Perceived knowledge and confidence change*

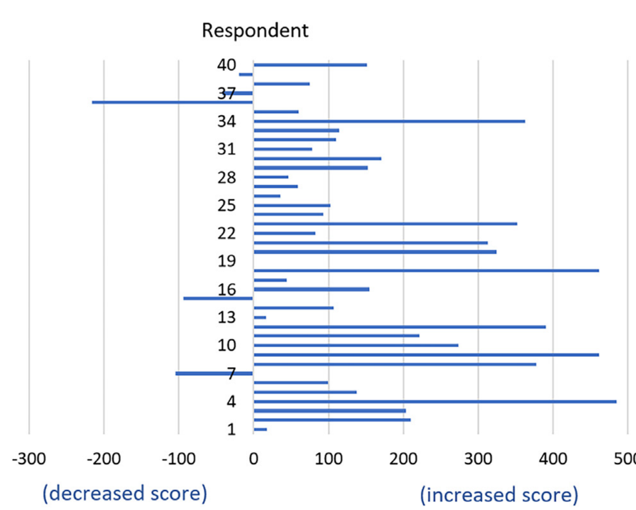


Figure 11*. Game score improvement from trial 1 to trial 3*

have increased. The average score has experienced a rise of 146.625.

Figure 12 depicts the completion time for a scenario at the same level. The boxplot of game completion time shows a decreasing trend from Trial 1 to Trial 2 and then to Trial 3, indicating an overall improvement in performance. Although the median values of Trial 2 and Trial 3 are nearly identical, the interquartile range is slightly reduced, suggesting a more consistent completion time in the later trial. Interestingly, the randomization of error scenarios across repeated trials led to various user experiences, as demonstrated by the differences in completion durations and scores between the second and third trials. Players were likely compelled to apply fundamental problem-solving principles rather than memorize solutions in randomized scenarios. This element of unpredictability may be crucial in the development of adaptable problem-solving abilities that are relevant to real-world situations. This randomized scenario also fits the experimental results by [37], which revealed that input randomness significantly impacted game satisfaction.

However, we noticed that regular game players typically possess a superior comprehension of game controls. Consequently, we examined the extent to which prior gaming habits affected user performance in resolving this issue. A question that emerged was whether individuals who regularly engaged in gaming could complete the game more swiftly. Respondents were requested to indicate whether they were individuals with a history of high general gaming frequency. An ANOVA test was performed to examine the impact of general gaming frequency (gamer vs. non-gamer) on average game score and completion time.

Figure 13 shows the box plot of the game scores on five different general gaming frequencies'. It indicates that there is no significant difference between categories. It is supported by the ANOVA results, the F-value of 0.219 suggests that the variance between the groups (gamers and non-gamers) is very small compared to the variance within the groups.

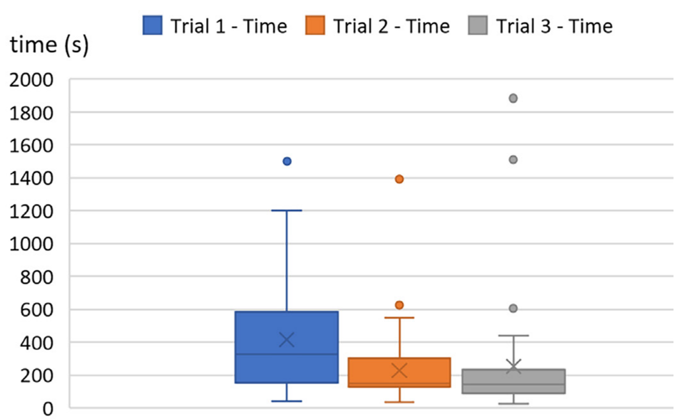


Figure 12. *Game completion time over multiple trials*

This indicates that there is little difference in average game scores between the two groups. The p-value (0.926) exceeds the significance level of 0.05, indicating no statistically significant difference in average game scores between gamer and non-gamer respondents.

Additionally, game completion time as illustrated in Figure 14, individuals with extensive prior gaming experience were not the fastest to finish this game. The ANOVA shows the F-value of 0.803, which indicates that the variability within the groups is not significantly greater than the difference between the group means. There is also insufficient evidence to confirm a statistically significant difference in the average game completion time between gamers and non-gamers, as the p-value (0.532) exceeds the conventional 0.05 significance threshold.

In the end, participants were asked to share their views on their perceived engagement and the effects following gameplay. Figure 15 illustrates a radar chart depicting respondents' perspectives on this matter. Their curiosity about further exploring this issue shows the greatest influence, with an average score of 4.4 out of 5. The minimum value is observed in the motivation to finish the game recorded at 4.275. This is feasible because they were instructed to compete at the same level three times, whereas players typically aspire to advance to the next level immediately. Overall, the game offers incentives through enhancing knowledge and achieves a commendable value above four on a five-point scale.

The findings of this study indicate a significant improvement in participants' knowledge and troubleshooting confidence

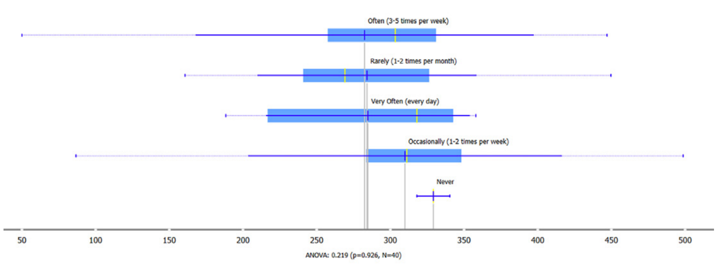


Figure 13. *Effect of general gaming frequency (gamer vs. non-gamer) on average game score*

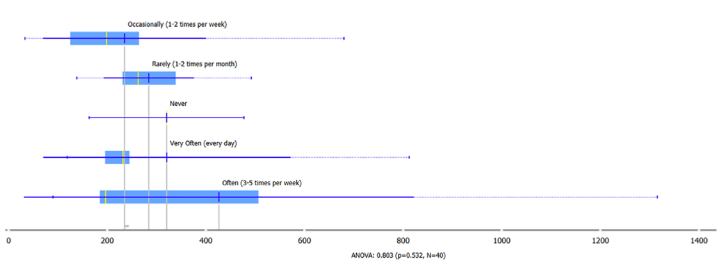


Figure 14. *Effect of general gaming frequency (gamer vs. non-gamer) on average game completion time*

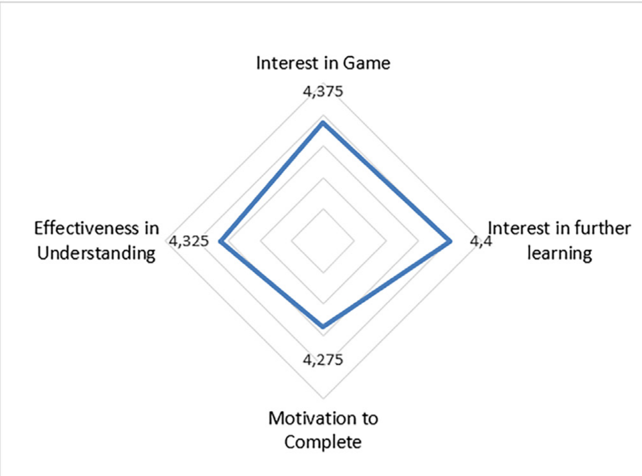


***Figure 15**. Participants' perceived engagement and learning impact*

after engaging in the multi-location scenario-based serious game. This aligns with prior research [38] emphasizing the significance of simulation-based learning in technical disciplines, with course assessments predominantly indicating that engaging in the virtual reality/simulation pre-labs enhanced student understanding of the concepts. In certain instances, it was designated as a favoured segment of the course. The cognitive and affective impact of the game was also evaluated based on participants' self-assessed knowledge and troubleshooting confidence. The observed increase in perceived confidence is consistent with the literature suggesting that simulation-based training significantly enhances students' confidence and practical comprehension [39,40].

6. Conclusion

This research demonstrates the creation of a serious game for marine electrical education, encompassing plenary design, multi-location scenario development, implementation, and evaluation. The game enables students to safely practice and enhance their skills in problem identification and mitigation by replicating detailed real-world challenges within an immersive virtual ship environment. The evaluation results indicate the efficacy of the serious game in enhancing the problem-solving abilities of marine electrical engineering students. Substantial improvements in both objective and perceived knowledge and confidence underscore the game's efficacy as an educational instrument, specifically in marine electrical engineering and broadly in MET. Future research could explore how adaptive learning elements might further tailor scenarios based on individual performance. Additionally, expanding the modular systems to encompass more diverse troubleshooting procedures could better reflect the range of challenges marine engineers face, thereby bridging theoretical knowledge and practical skill development in marine electrical troubleshooting.

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Footnotes

Authorship Contributions

Concept design: R. Riantini, M. Hariadi, S. M. S. Nugroho, D. P. Wulandari, and N. R. Dwihartantyo, Data Collection or Processing: R. Riantini, and N. R. Dwihartantyo, Analysis or Interpretation: R. Riantini, M. Hariadi, and S. M. S. Nugroho, Literature Review: R. Riantini, and D. P. Wulandari, Writing, Reviewing and Editing: R. Riantini, M. Hariadi, S. M. S. Nugroho, and D. P. Wulandari.

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