A Game-Based Learning Model for Basic Life Support Using First-Person Interactive Simulation

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***Abstract*—Previous BLS and first-aid learning studies largely rely on traditional face-to-face training or low-fidelity digital approaches, which are often costly, time-consuming, and inaccessible to many learners, especially laypersons. Many serious games focus primarily on awareness and conceptual knowledge, rather than procedural mastery and real-time decision-making. In addition, most existing games lack high-fidelity first-person immersion, provide limited real-time feedback, and are not aligned with localized national medical protocols, reducing their realism and contextual relevance. To address these gaps, this study proposes the development of a 3D game-based learning model using first person interactive simulation, designed to educate users on Basic Life Support (BLS) procedures in cardiac arrest scenarios. Unreal Engine 5.4 was utilized to create an immersive and realistic environment where players engage in critical emergency steps, real-time visual prompts and audio feedback, and decision-making under pressure, rather than passive content delivery. Importantly, it strictly follows the Ministry of Health Malaysia's BLS guidelines, ensuring procedural accuracy and local relevance. This approach bridges the gap between theoretical knowledge and practical application, while providing a scalable, accessible, and engaging alternative to conventional BLS training. Through this educational serious game, players are empowered to gain confidence and practical understanding of life-saving procedures, ultimately contributing to greater public preparedness in real-world emergencies.**

Keywords*—Basic life support; emergency; simulation; game-based learning; serious games

I. Introduction

Basic Life Support (BLS) is a crucial set of medical interventions that can significantly increase their chances of survival for those experiencing sudden cardiac arrest, choking, or other life-threatening situations [1, 2]. Both medical professionals and the general public are generally advised to perform cardiopulmonary resuscitation (CPR) technique. CPR is a life-saving emergency procedure that is carried out when the heart stops beating. In order to preserve oxygenation and circulation during cardiac arrest, it combines rescue breathing with chest compressions. Despite their proven effectiveness, many people lack the confidence, awareness, or practical knowledge to apply them correctly. In emergency situations, hesitation or mistakes can cost precious seconds and ultimately a life [3, 4]. Access to quality BLS training is a significant concern.

Conventional training methods often require participants to attend physical workshops or formal certification classes, which can be expensive, time-consuming, and not always available to those in rural or underserved areas. Furthermore, once the training is completed, there are few opportunities to practice these skills regularly. Without consistent reinforcement or hands-on repetition, individuals tend to forget the exact steps, especially when faced with the stress and pressure of real-life emergencies [5, 6]. These gaps between learning and application can leave many bystanders unprepared when someone around them requires urgent care. Moreover, traditional instructional methods are typically passive, relying heavily on lectures or video demonstrations. While informative, these methods may not be sufficient for instilling the muscle memory and critical thinking needed to act confidently during high pressure situations. For learners who do not have access to mannequins or realistic practice scenarios, it becomes even harder to simulate real-world experiences. Without engaging, interactive components, BLS training can feel distant and theoretical, rather than practical and applicable [3 - 6].

Motivated by these limitations, this study proposes the development of a 3D first-person simulation game. This game offers a virtual platform where users can immerse themselves in realistic emergency scenarios that require immediate action. Players will be guided step-by-step through the processes of checking responsiveness and initiating CPR—mirroring real-life protocols, based on the Ministry of Health Malaysia (MOH) guidelines [1]. The simulation will allow users to navigate through dynamic environments, manage obstacles, and respond quickly to changing conditions. By integrating real-time visual and audio feedback, timing-based performance metrics, and structured task progression, the simulator aims to promote procedural accuracy, reinforce correct decision-making, and build user confidence under time pressure.

Ultimately, this study seeks to bridge the gap between theoretical knowledge and practical application in BLS training by providing an accessible, scalable, and engaging digital learning tool. Through high-fidelity simulation and game-based interaction, the proposed system aspires to

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enhance public preparedness for medical emergencies and to serve as a complementary training resource for educational institutions, community programs, and self-directed learners. Accordingly, this study advances the state of the art in game-based BLS training by demonstrating how protocol-enforced interaction and timing-based performance analytics can produce measurable procedural learning gains among non-expert users.

Beyond system implementation, this study contributes new methodological and empirical insights to the field of game-based medical education. Specifically, it demonstrates how a protocol-enforced interaction model—where progression is conditionally gated by correct procedural execution—can be effectively operationalized within a first-person simulation to support procedural fidelity in BLS training. The study further provides empirical evidence that integrating timing-based psychomotor performance feedback, rather than binary correctness indicators alone, contributes to meaningful improvements in learners' procedural understanding. These insights are validated through quantitative learning gain analysis, which reveals substantial normalized gains among lay participants with limited prior BLS experience. Collectively, the findings offer transferable design and evaluation principles for future serious games aimed at emergency response training, extending beyond the specific system presented in this work.

TABLE I. OVERVIEW OF GAME-BASED FOR FIRST AID LEARNING

Author	Target Audience	Platform / Technology	Results / Outcome
Efe & Topsakal [13]	Primary school pupils.	Digital educational games used in classroom sessions.	Improved first-aid awareness and positive acceptability among pupils (qualitative gains reported).
Boada et al. [14]	General public (focus on choking scenarios).	Serious game composed of mini games (web / mobile–friendly design)	Demonstrated usability and effectiveness for teaching choking procedure; supported stepwise learning of actions.
Rebollo et al. [21]	General citizens	Mobile video-game / progressive web app (challenge-based mobile delivery).	Gamified mobile approach shown viable for first-aid instruction, improving engagement and accessibility.
Darotin et al. [22]	School students and community laypersons (burns-focused)	E-Fa Game — community/school educational game	Reported knowledge improvement on burn first-aid among participating students in community programs.
Benkhedda & Bendella [23]	General public / trainees for emergency first aid	3D serious game with Multi-Agent System integration (desktop 3D environment; agent-driven NPCs).	Presented an adaptive, agent-based architecture to enhance realism and collaborative decision-making (paper emphasizes architecture and potential rather than large-scale empirical results).

II. RELATED WORKS

A. Computer Simulation

Computer simulation is the use of computer models to replicate real-world processes, systems, or events in a virtual environment [7 – 10]. It allows users to test scenarios, predict outcomes, and practice skills without the risks, costs, or limitations of real-life trials. By mimicking reality through algorithms and data, simulations are widely applied in fields such as education, engineering, healthcare, and gaming. In learning contexts, computer simulation provides an interactive and safe platform where learners can engage in hands-on practice, visualize abstract concepts, and improve decision-making and problem-solving skills [7 – 10].

A randomized clinical trial was carried out by Habibli et al. [10] to test how simulation-based education affects nursing students' knowledge and performance of adult basic life support CPR. The study shows that simulation-based BLS-CPR education boosts both nursing students' knowledge and hands-on performance, not just in the short term but with retention after three months. The authors suggest integrating conventional teaching with simulation gives better learning for BLS among nursing students.

A study by Berger et al. [9] found that combining Problem-Based Learning (PBL) with high-fidelity simulation enhances immediate CPR skills compared to classical hands-on training. These findings underline that simulation-based education is most effective when learners receive timely feedback, deliberate practice, and curriculum integration [11]. The present simulator builds on these principles by embedding immediate feedback systems and realistic scenario progression, thereby strengthening transfer of learning to real-world emergency contexts.

B. Game-Based Learning

Game-based learning represents a crucial innovation in BLS training, with technological advancements enhancing its efficacy [6 – 7, 12]. Researchers have identified that integrating game mechanics motivates learners and increases their engagement levels in emergency response scenarios—a key factor in successful training. Within this framework, learners engage with content through digital simulations that resemble real-world scenarios, providing a hands-on experience that traditional didactic methods struggle to replicate. Table I shows overview of several studies that implement game-based or serious games for first aid learning.

While prior studies have explored serious games, 3D environments, and interactive simulations for first aid and CPR education, the contribution of this work lies not merely in graphical fidelity or first-person immersion, but in the manner procedural knowledge is operationalized, enforced, and evaluated during gameplay.

Unlike many existing systems that emphasize awareness, free exploration, or conceptual understanding, the proposed simulator adopts a strictly sequenced, protocol-driven interaction model aligned with the Ministry of Health Malaysia's official BLS guidelines. Each stage of the BLS process is conditionally gated, preventing progression unless correct actions are performed within defined temporal and procedural constraints. This design promotes procedural fidelity and reduces the risk of incorrect habit formation, which remains a limitation in several existing serious games.

Furthermore, the simulator advances beyond common real-time feedback mechanisms by incorporating timing-based psychomotor performance metrics, particularly during chest compression tasks, where user input is evaluated against clinically recommended compression rates and consistency thresholds. Rather than providing binary success or failure feedback, the system supports formative learning through immediate corrective cues, retry loops, and embedded micro-assessments that reinforce both conceptual understanding and motor execution.

Importantly, the effectiveness of this approach is empirically validated through quantitative learning gain analysis, demonstrating a high normalized gain (Hake's g = 0.73) among lay users with limited or no prior BLS training. This combination of protocol-enforced interaction, psychomotor evaluation, and measurable learning improvement distinguishes the proposed system from existing game-based BLS training solutions that primarily report usability, engagement, or qualitative outcomes.

Consistent with the findings of Gorbanev et al. [15], user engagement in educational games correlates strongly with interactivity and feedback quality. The simulator's real-time cues, task progression, and responsive CPR performance transform learning into an interactive performance evaluation process, sustaining user motivation and self-efficacy [16].

C. Pedagogical Implications and Training Integration

1) From a pedagogical perspective, the simulator supports experiential and constructivist learning principles, enabling players to learn by doing, reflecting, and iterating within authentic contexts. The embedded feedback loop (action → evaluation → correction) aligns with Kolb's experiential learning cycle [19], ensuring that learners not only memorize BLS steps but internalize them through repeated performance.

2) Moreover, the simulator has strong potential for integration into public health education and institutional training programs. It may serve as a complementary digital tool in schools, universities, and healthcare workshops, reducing the dependency on physical mannequins and in-person sessions. Institutions can deploy the simulator for pre-assessment, refresher courses, or blended training models, supporting large-scale skill dissemination aligned with Malaysia's national emergency preparedness agenda.

III. METHODOLOGY

This study adopts the Game Development Life Cycle (GDLC) model to develop a 3D first-person simulation game for BLS learning [16, 17]. GDLC model was chosen due to its clarity, linear structure, and suitability for solo or small-team projects [18]. It consists of three primary phases: Pre-production (Phase 1), Production (Phase 2) and Post-production (Phase 3) as shown in Fig. 1. Every stage is essential in order to make sure the game achieves its goals for gameplay and learning. The scope of this study includes the design of realistic environments based on common emergency settings like homes, kitchens, and public parks. The target audience is students, educators, and the general public. The project's direction is to blend educational value with gameplay elements to enhance knowledge retention and boost user confidence in performing life-saving interventions.

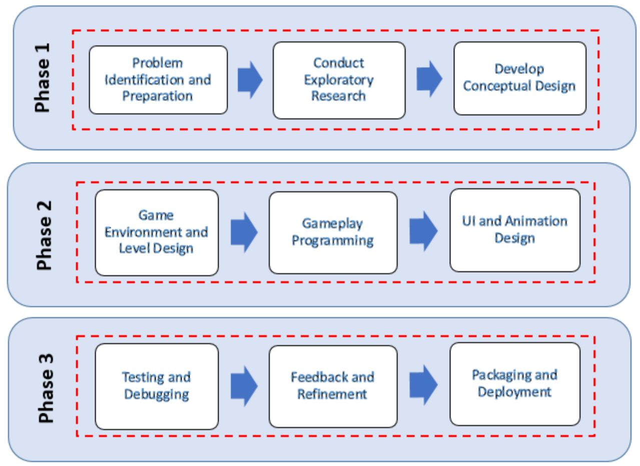

Fig. 1. Flowchart of research methods.

A. Pre-production Phase

In this phase, foundational planning and design were carried out. All key decisions were made regarding the game's concept, learning objectives, technical requirements, and design strategies. This phase focused heavily on understanding real-world CPR protocols and translating them into an engaging, educational gameplay experience.

The initiative was motivated by the shortcomings of conventional BLS training techniques, including low learner engagement, lack of feedback, and restricted access to realistic practice scenarios [3. 5. 6]. Research was conducted using academic literature, official BLS training manuals from MOH to identify critical BLS steps that should be included in the game [1]. These steps include checking for danger, response, calling emergency services, and performing chest compressions. Based on the research, the concept was developed for a first-person 3D simulation game that places the player in a cardiac arrest scenario. The player must complete each BLS step in sequence through interactive gameplay, mimicking real-life responses. The goal was to provide a guided learning experience that reinforces correct actions and decision-making under pressure.

This study outlined both functional and non-functional requirements. Functionally, the game must simulate BLS steps, provide user feedback (e.g., "Correct!" or "Try Again"), and award points based on performance. Non-functional requirements included usability, visual clarity, and real-time responsiveness. Hardware and software requirements were also determined, including the use of Unreal Engine 5.4 for development and Windows PC as the deployment platform.

A detailed Game Design Document (GDD) was created to outline the gameplay structure, User Interface (UI) flow, scoring system, and technical assets. The document served as a roadmap throughout the project, helping to guide the development of core mechanics such as the CPR meter, input detection (e.g., pressing 'E' or clicking on prompts), and condition-based game logic. It also included planning for player animations, background environment, user interface layout, and sound integration. By the end of the pre-production phase, a clear blueprint for the game was established, ensuring a smooth transition into the production phase with well-defined goals and expectations.

B. Production Phase

1) This phase represents the core of the development process, where the concepts and designs from the pre-production stage are transformed into a fully functional game. A realistic 3D environment was created to simulate an emergency scenario, such as a victim collapsing in a public space. The layout was designed to guide the player intuitively from one BLS step to the next. Key interactive objects (e.g., the patient, emergency phone) were placed with visual cues to ensure player clarity.

2) The game's logic was implemented using Unreal Engine's Blueprint system, which allowed for visual scripting of interactions and events. Conditional branches ensured that players had to follow the correct sequence before progressing, mimicking the structured nature of real CPR training. Each BLS step was programmed to respond to specific user inputs

3) Animations for CPR hand placement and character behaviors were either created or triggered through Blueprints. Hand placement on the chest was particularly important to reflect correct technique. Some animations were implemented to enhance realism, especially during chest compressions.

C. Post-production Phase

This final phase focused on refining the game experience through testing, feedback, and deployment. For the BLS simulation game, this phase ensured that the game met its educational goals, operated without major bugs, and delivered a smooth and engaging user experience. The game underwent multiple rounds of internal playtesting to identify bugs, logic errors, and UI issues. Specific test cases included:

- Verifying the correct sequence of BLS steps (e.g., player cannot skip directly to CPR).
- Ensuring all input actions (mouse clicks, key presses) triggered the intended response.
- Detecting misaligned animations, faulty hand placements, or delayed audio playback.
- Monitoring performance issues such as lag or long load times.

Blueprint-based logic was debugged by using print statements and execution flow visualization in Unreal Engine. Several common issues such as UI not updating, the player getting stuck, or input not being detected were resolved in this phase. Then, feedback was gathered from peers and instructors during informal user testing. Suggestions such as improving prompt clarity, adding clearer success/failure messages, and enhancing the timer's visibility were incorporated. Refinements also included:

- Adjusting CPR meter thresholds to balance difficulty.
- Smoothing animation transitions.
- Replacing placeholder assets with higher-quality visuals or sounds when needed.

This feedback-driven polishing ensured that the game was both educational and enjoyable. Once testing and improvements were complete, the game was packaged using Unreal Engine 5.4's built-in packaging tools for Windows (64-bit). The final build was exported as an executable file (.exe), ready for distribution. The packaged game included all necessary assets, settings, and dependencies required to run the game on any compatible Windows PC. The game was then made available for sharing and demonstration, allowing players to engage with an interactive BLS scenario anytime, without needing physical training equipment.

IV. Implementation

The game was implemented as a first-person simulation, allowing the player to take the role of a bystander responding to a cardiac arrest victim. The player navigates the environment and interacts with prompts to progress through each step of Basic Life Support. The core components of the game include:

- Game Mode Blueprint: Controls the state of the game (e.g., win/loss conditions).
- Player Character Blueprint: Handles user movement, interaction, and BLS actions.
- User Interface Widgets: Displays feedback, instructions, CPR meter, and timer.
- Timer System: Limits time to complete actions to simulate urgency.
- Trigger Boxes: Detect player position and activate events like Danger Check.

A. User Interface

Widget Blueprints were used to create the UI elements, ensuring they responded dynamically to in-game events. The UI was designed to be minimal but informative, which included:

- Step-by-step instructions. Text prompts guide the player.
- A countdown timer that added urgency to simulate real-life stress.
- Feedback is provided visually and through sound, helping reinforce correct actions.
- A quiz-style system checks if the selection is correct before continuing.
- Feedback Messages: "Correct!", "Wrong!"

Each BLS step was programmed to respond to specific user inputs:

- Danger check: activated by approaching the patient as shown in Fig. 2.

Fig. 2. UI of danger check.

- Response check: Interaction with key prompts and audio.
- Call for help: Player needs to answer the quiz as shown in Fig. 3 to simulate calling 999.
- Airway check: Players are shown two images as shown in Fig. 4 and must click the correct version representing an open airway.

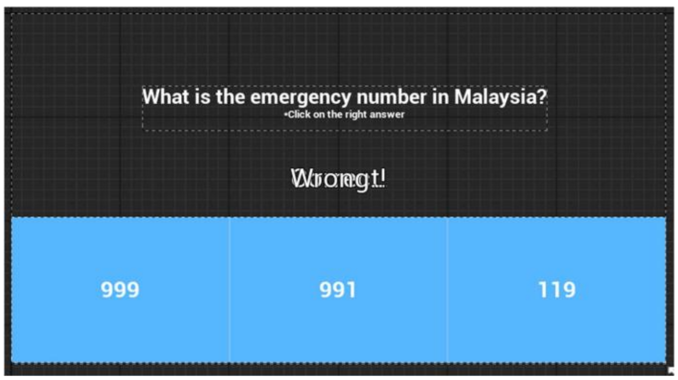

Fig. 3. UI of call for help.

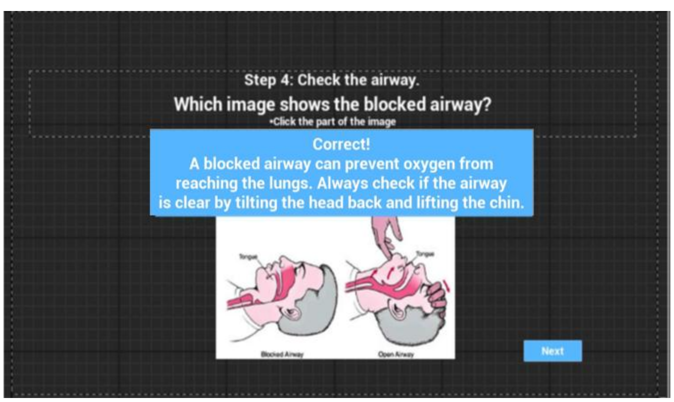

Fig. 4. UI of airway check. Airway image adopted from [20].

- Breathing check: triggered by key prompts to check breathing in 5 to 10 seconds.
- CPR chest compression (refer Fig. 5): involved pressing the correct key at the right time within a percentage range to score successful compressions (100 to 120 compressions per minute).

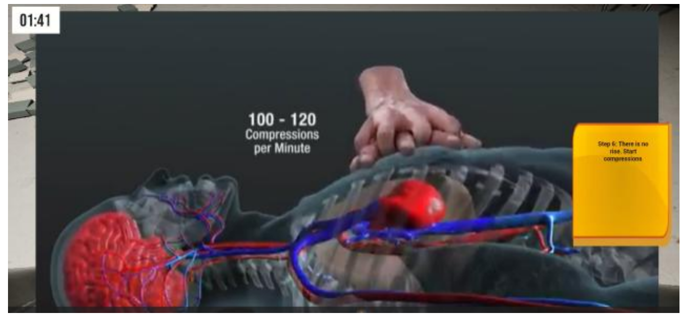

Fig. 5. UI of CPR chest compression.

B. Learning Flow and Key Gameplay Stages

The simulator demonstrates a clear and pedagogically grounded learning flow. Each gameplay stage reflects the four components of experiential learning theory, enabling players to learn BLS procedures through direct experience, feedback, concept reinforcement, and repeated practice. Table II summarizes pedagogical mechanisms in each gameplay stage.

The structured sequence—from danger assessment to breathing evaluation—ensures that learners are guided progressively through each critical step of the BLS process, reducing cognitive load while reinforcing procedural accuracy. Immediate corrective prompts, visual cues, and context-specific quizzes function as formative assessments that strengthen conceptual understanding and support error-based learning in a risk-free environment.

TABLE II. SUMMARY OF PEDAGOGICAL VALUE

Gameplay Stage	Pedagogical Mechanism
Danger check	Scaffolding, situated learning: Learner understands safety awareness
Response check	Experiential learning: Builds correct procedural memory
Calling 999	Cognitive apprenticeship & reinforcement: Teaches urgency
Airway quiz	Dual coding & error-based learning: Strengthens visual understanding of airway management
Breathing check	Procedural reinforcement: Helps learners remember correct timing and method
Transition to CPR	Scaffolding & load reduction: Smooth conceptual shift before CPR stage
UI prompts & feedback	Behaviourist reinforcement: Improves retention and user confidence

C. Feedback and Scoring Flow

Based on Fig. 6, the simulator begins by initializing the environment and activating a three-minute timer before presenting step-by-step BLS instructions. For each stage, the player performs the required action, and the system checks its correctness. Incorrect actions trigger an error prompt and allow the player to retry, while correct actions generate positive feedback and progress the flow. Throughout gameplay, the timer continuously evaluates performance, where exceeding the time limit results in failure. If the player completes all BLS steps correctly within the allotted time, the simulation ends successfully when rescue arrives, producing a time-based performance result.

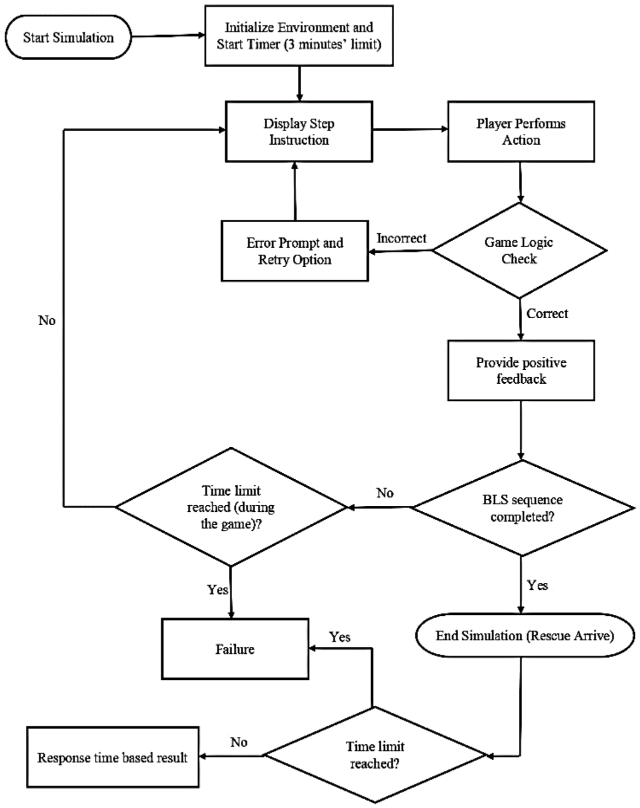

Fig. 6. Feedback and scoring flow.

V. Results and Discussion

The evaluation of this study was conducted to measure both knowledge improvement and usability of the simulator as a BLS training tool. Two types of data collection were used: quantitative analysis (pre-posttest and inferential statistics) and qualitative analysis (open-ended feedback from participants).

A. Quantitative Analysis

A total of 16 participants were involved in the evaluation of the simulator. The participants were recruited from various backgrounds to ensure a mix of ages and levels of prior exposure to BLS. Participants ranged from below 18 years old to above 45 years old, representing both younger learners and adult users. This range was chosen to reflect the fact that sudden cardiac arrest can occur in any environment, and bystanders of different age groups may be required to perform BLS. Out of the 16 participants, 6 had non-certified prior training in BLS (such as school-based or workplace awareness programs), while 10 had no previous training. None of the participants held certified medical qualifications. This distribution highlights the simulator's role as an accessible training tool for individuals with little to no prior exposure.

Participants reported varied levels of familiarity with digital games and simulations, ranging from rare users to frequent players. This factor was important since game-based learning systems may present a steeper learning curve for those unfamiliar with interactive environments. When asked about their confidence in performing CPR, the majority rated themselves at 2 or on a 5-point scale, indicating low initial confidence.

The pre-posttest was administered before and after participants engaged with the simulator to measure learning improvement. The test consisted of 10 multiple-choice questions covering the BLS sequence and key emergency steps. The learning improvement achieved through the simulator was examined using both learning gain analysis including Hake's normalized gain [24] and McNemar's test [25] on item-level correctness data.

The average pre-test score was 6.0 out of 10, while the average post-test score was 8.9 out of 10, indicating a 28% improvement in knowledge. Fig. 7 shows the comparison of the pre-test and post–test results. The normalized learning gain (Hake's g) was calculated to be 0.73 as shown in Table III, which falls within the category of high gain, indicating that the simulator facilitated substantial conceptual improvement, especially for novice learners.

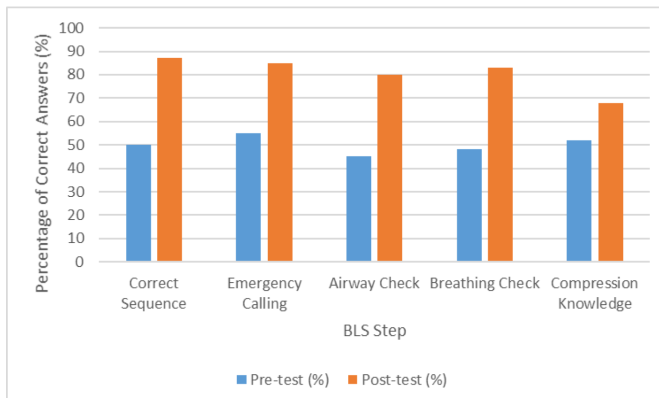

Fig. 7. Comparison of pre-test and post-test results.

To complement this overall score analysis, McNemar's test was conducted to evaluate changes in correctness for each BLS step at the item level. Based on Table IV, significant improvements were found for the Correct Sequence ($\chi^2 = 4.17$, $p = .041$) and Airway Check ($\chi^2 = 4.17$, $p = .041$), demonstrating that the simulator was particularly effective in reinforcing the procedural order of BLS and improving recognition of proper airway assessment. While Emergency Calling ($\chi^2 = 3.20$, $p = .074$) and Breathing Check ($\chi^2 = 3.20$, $p = .074$) showed notable increases in percentage correctness, these changes did not reach statistical significance. Compression Knowledge also improved in correctness but not significantly ($\chi^2 = 1.33$, $p = .248$), suggesting that this area may require more targeted reinforcement in future versions of the simulation.

Together, the high normalized learning gains and the significant item-level improvements demonstrate that the simulator effectively strengthened participants' understanding and application of key BLS steps. The findings highlight that the interactive, step-guided format was especially beneficial for conceptual sequencing and airway assessment—areas critical for real-world emergency response—while also identifying components such as compression technique that may benefit from enhanced feedback or additional practice features. Although the sample size limits the generalizability of these findings, the strong magnitude of the observed learning gains suggests a robust signal of efficacy. Consistent with recommendations for the evaluation of novel serious game interventions, this initial evaluation confirms the feasibility and immediate didactic effectiveness of the simulator.

TABLE III. LEARNING GAIN RESULTS

BLS Component	Pre-test (%)	Post-test (%)	Gain (%)	Category
Correct Sequence	50	87	+37	High Improvement
Emergency Calling	55	85	+30	Moderate Improvement
Airway Check	45	80	+35	High Improvement
Breathing Check	48	83	+35	High Improvement
Compression Knowledge	52	68	+16	Low Improvement
Overall score	Mean = 6.0	Mean = 8.9	+2.9 (28%)	Hake's g = 0.73 (High Gain)

TABLE IV. FINAL MCNEMAR RESULT TABLE

BLS Component	McNemar's χ^2	*p*-value	Statistical Interpretation
Correct Sequence	4.17	0.041	Significant Improvement
Emergency Calling	3.20	0.074	Not Significant
Airway Check	4.17	0.041	Significant Improvement
Breathing Check	3.20	0.074	Not Significant
Compression Knowledge	1.33	0.248	Not Significant

B. Qualitative Analysis

Qualitative data was collected from participants through open-ended questions and observer notes during gameplay. This provided deeper insights into user experience, perceptions of realism, and areas for improvement that could not be captured by numerical scores alone. Participants consistently highlighted the following positive aspects of the simulator. Firstly, the step-by-step prompts were considered very helpful in guiding users through the BLS sequence. Several participants mentioned that the clear instructions reduced confusion, especially for first-time learners.

Real-time feedback was praised for making compressions more engaging and allowing players to understand whether they were performing the action correctly. Furthermore, immersive simulation environment provided a sense of realism that helped users imagine responding in a real-life emergency. These elements were identified as the core strengths that supported knowledge retention and confidence-building.

While the simulator was well-received overall, several weaknesses were noted. Airway quiz visuals were described as unclear, which made some participants unsure whether their choices were correct. Next, the timer mechanism was reported to cause stress among beginners. Some participants felt pressured to complete actions too quickly, which affected their ability to follow the correct sequence calmly. Moreover, PC-only platform limitation reduced accessibility. Several participants expressed interest in mobile or VR versions that could allow more flexible use.

VI. CONCLUSIONS AND FUTURE WORK

This study presented the design, development, and evaluation of a 3D first-person interactive simulation for BLS training, aimed at improving procedural understanding and learner confidence among lay users. The simulator successfully operationalized nationally recognized BLS guidelines from the Ministry of Health Malaysia into a protocol-enforced, step-by-step interactive experience that emphasizes procedural accuracy, real-time decision-making, and psychomotor performance. Through immersive gameplay, timing-based feedback, and structured task progression, the system enabled users to practice life-saving interventions in a safe and repeatable virtual environment. The empirical evaluation demonstrated substantial learning improvements, as evidenced by a high normalized learning gain, indicating the effectiveness of the proposed approach in strengthening procedural knowledge among non-expert participants. The findings of this study contribute to the broader understanding of how procedural enforcement and psychomotor feedback mechanisms influence learning outcomes in simulation games for emergency medical training.

Beyond system development and evaluation, the findings of this study carry broader implications for public health education and emergency preparedness. The simulator illustrates how game-based, first-person simulations can serve as scalable and accessible tools for public BLS education, particularly in contexts where traditional face-to-face training is limited by cost, infrastructure, or instructor availability. By lowering barriers to practice and enabling repeated exposure to realistic emergency scenarios, such digital training tools have the potential to enhance community-wide readiness and increase the likelihood of timely bystander intervention during cardiac arrest events.

It is important to acknowledge several limitations of this study that may influence the interpretation and generalizability of the findings. First, the evaluation involved a relatively small sample size and was limited primarily to lay users without certified medical training; therefore, the results may not fully represent learning outcomes across broader populations, such as healthcare professionals or certified first aid instructors. Second, the study focused on short-term knowledge improvement measured immediately after gameplay, and did not examine long-term retention or transfer of skills to real-world emergency situations. Third, although the simulator incorporates timing-based psychomotor feedback, it does not replace physical hands-on practice with mannequins, which remains essential for developing tactile accuracy in CPR performance. Additionally, the current implementation is limited to a desktop platform, which may restrict accessibility for wider adoption. Recognizing these limitations provides a balanced interpretation of the results and highlights opportunities for future research to extend the scope, robustness, and applicability of game-based BLS training.

Therefore, several directions for future work are proposed to enhance the simulator. One important step is to expand the scope of emergency scenarios. While this project focused primarily on cardiac arrest, future development should integrate additional cases such as choking, drowning, and the use of automated external defibrillator (AED). Another avenue for improvement is the expansion of platform accessibility. Developing mobile and Virtual Reality (VR)-compatible versions of the simulator would allow a broader audience to engage with the system.

While the proposed simulator demonstrates practical value for large-scale dissemination of BLS training, further research is necessary to strengthen its empirical validation and broaden its applicability. The current evaluation involved a limited sample size of 16 participants, which provided useful initial insights but restricts the generalizability of the findings. Future studies should therefore focus on larger-scale user evaluations involving more diverse participant groups, including healthcare professionals, certified first aid trainers, and broader community populations. Such evaluations would enable a more rigorous assessment of the simulator's accuracy, effectiveness, and adaptability across different user expertise levels. With expanded validation, the software-based nature of the simulator positions it well for integration into schools, universities, community programs, and workplace safety initiatives as a supplementary or preparatory learning resource. The protocol-enforced interaction model further supports consistency in instructional delivery, making the system suitable for standardized training environments and blended BLS education models, where it may function effectively as a pre-training module, refresher tool, or formative assessment mechanism.

In terms of usability and system design, improving interaction features should be prioritized. Enhancements could include redesigning unclear quiz visuals, refining the timing mechanism to adjust difficulty based on user experience, and offering multiple learning modes, such as beginner and advanced. Finally, the feedback and scoring system can be expanded into a more detailed analytics tool. Instead of providing only basic real-time prompts, future versions could track accuracy and performance consistency across different steps of the BLS process.

In conclusion, the simulator demonstrates potential for integration into formal training and certification pathways. While it does not replace hands-on practice with mannequins or instructor-led assessment, the simulator can complement existing certification programs by reinforcing procedural sequencing, decision-making under pressure, and conceptual understanding prior to or between physical training sessions. In this regard, this study contributes empirical evidence that well-designed serious games can extend beyond experimental prototypes to become meaningful components of structured emergency response education. Overall, this work positions immersive, protocol-driven simulation as a viable and impactful approach for advancing BLS training, strengthening public health education strategies, and enhancing societal preparedness for medical emergencies.

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