

Jurnal Info Kesehatan

Vol. 24, No. 1, March 2026, pp. 88-102

P-ISSN 0216-504X, E-ISSN 2620-536X

DOI: [10.31965/infokes.Vol24.Iss1.2331](https://doi.org/10.31965/infokes.Vol24.Iss1.2331)

Journal homepage: <https://jurnal.poltekkeskupang.ac.id/index.php/infokes>



RESEARCH

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Web-Based Electrocardiography Learning Application Development for Basic Trauma and Cardiac Life Support Training

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Received: 6 January 2026

Revised: 19 January 2026

Accepted: 10 February 2026

Abstract

Electrocardiography (ECG) interpretation is an essential competency for healthcare providers, particularly nurses, in managing cardiac emergencies during Basic Trauma and Cardiac Life Support (BT&CLS). However, ECG learning in BT&CLS training is still predominantly delivered through conventional, paper-based methods, which may limit learners' ability to rapidly and accurately interpret cardiac rhythms. Advances in web-based learning offer opportunities to enhance flexibility, interactivity, and learner engagement in emergency care education. This study aimed to develop and evaluate a web-based ECG learning application for BT&CLS training, focusing on its usability and technology acceptance. This study employed a mixed-method Research and Development (R&D) design combined with a quantitative approach. The web-based application was designed to include ECG theory modules, rhythm interpretation exercises, interactive quizzes with immediate feedback, and progress tracking features. Usability was assessed using an adapted System Usability Scale (SUS), while technology acceptance was measured using a modified Technology Acceptance Model (TAM) questionnaire. A total of 31 participants involved in BT&CLS training were recruited. Instrument reliability testing demonstrated excellent internal consistency. The results indicated high levels of user agreement across all usability dimensions, including functionality, reliability, ease of use, and portability of the application. Furthermore, all TAM components perceived usefulness, perceived ease of use, user attitude, behavioral intention, and user trust were rated in the high category. Participants reported that the application was intuitive, supportive of self-paced learning, and relevant to the competencies required in BT&CLS training. Overall usability and technology acceptance findings indicate that the web-based application effectively addresses key limitations of traditional paper-based ECG learning by enhancing flexibility, interactivity, and learner engagement in BT&CLS training. These findings suggest that digital learning tools can support self-paced practice and reinforce ECG interpretation competencies required in emergency care contexts. The developed web-based ECG learning application demonstrated strong usability and high technology acceptance among BT&CLS trainees. The application shows substantial potential to be integrated into BT&CLS training programs as a complementary learning tool, supporting flexible, interactive, and learner-centered acquisition of ECG interpretation skills. Further studies are recommended to evaluate its effectiveness in improving learning outcomes and clinical performance in emergency settings.

Keywords: Electrocardiography, Basic Trauma, Cardiac Life Support, Technology Acceptance Model, Web-Based Learning.

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1. INTRODUCTION

Electrocardiography (ECG) is a fundamental tool in cardiovascular assessment and plays a critical role in the early recognition and management of acute cardiac conditions, particularly in emergency and critical care settings (Byrne et al., 2023). Accurate and timely ECG interpretation is essential for clinical decision-making in life-threatening situations such as cardiac arrest and acute coronary syndromes (Soar et al., 2021). Nurses, as frontline responders in emergency care, are frequently required to interpret ECG findings rapidly, making ECG interpretation a core professional competency with direct implications for patient safety and clinical outcomes. Basic Trauma and Cardiac Life Support (BT&CLS) training aims to enhance healthcare providers' preparedness in managing trauma-related injuries and cardiovascular emergencies. Within this framework, ECG interpretation supports rapid rhythm recognition and timely initiation of life-saving interventions (Dahbi et al., 2025). Despite its importance, ECG instruction in BT&CLS programs remains predominantly instructor-centered and paper-based, offering limited opportunities for interactive learning, repeated practice, and immediate feedback elements essential for developing complex interpretive skills (Rahimpour et al., 2021).

ECG interpretation requires more than theoretical knowledge; it involves visual pattern recognition and clinical reasoning developed through repeated exposure to diverse rhythm presentations (Krasne et al., 2021). Time constraints inherent in intensive BT&CLS courses further limit individualized learning and reinforcement, which may result in insufficient confidence and accuracy among trainees (Viljoen et al., 2020). These limitations highlight the need for innovative educational approaches that support sustained skill development beyond traditional instructional methods. Advances in information and communication technologies have facilitated the integration of technology-enhanced learning in health professions education (Car et al., 2022). Web-based learning platforms offer flexible access, learner-controlled pacing, and the ability to integrate multimedia and interactive components aligned with adult learning principles (Giebel et al., 2023). In ECG education, digital learning approaches have demonstrated improvements in rhythm recognition accuracy and learner confidence by enabling repeated practice and immediate feedback (Kashou et al., 2024).

However, the effectiveness of educational technology depends not only on instructional quality but also on system usability and user acceptance (Urstad et al., 2021). Applications perceived as difficult to use or misaligned with learners' needs may face resistance, regardless of their educational value. The System Usability Scale (SUS) and the Technology Acceptance Model (TAM) are widely used frameworks for evaluating usability and acceptance, providing insights into perceived ease of use, usefulness, and intention to use technology (Cheah et al., 2023). Despite their extensive application, limited research has examined the use of SUS and TAM in evaluating web-based ECG learning specifically designed for BT&CLS training. Existing studies largely focus on general e-learning systems or simulation-based education, without addressing the unique cognitive demands of ECG interpretation in life support training contexts (Lee et al., 2025). This gap underscores the need for context-specific digital solutions accompanied by rigorous evaluation of usability and acceptance. Accordingly, this study aimed to develop a web-based ECG learning application tailored to BT&CLS training and to evaluate its usability and technology acceptance using adapted SUS and TAM frameworks. By prioritizing usability and acceptance as prerequisites for sustainable implementation, this study contributes evidence to inform the design and integration of user-centered digital learning tools in emergency care education.

2. RESEARCH METHOD

This study employed a mixed-method design that integrated a Research and Development (R&D) approach with quantitative evaluation to develop and assess a web-based ECG learning application for Basic Trauma and Cardiac Life Support (BT&CLS) training. The R&D

approach enabled a systematic process of application design, validation, and refinement, while quantitative methods were used to evaluate usability and technology acceptance. This integration allowed for a comprehensive assessment of both instructional quality and user responses. The development phase began with a needs assessment and content analysis based on BT&CLS guidelines, relevant literature, and current emergency cardiovascular care standards. Learning materials were structured into modules covering fundamental ECG concepts, normal sinus rhythm, common arrhythmias, and emergency management relevant to BT&CLS scenarios. Interactive features, including ECG simulations, practice interpretation exercises, and quizzes with immediate feedback, were incorporated to support active learning. The application was developed as a responsive web-based platform using user-centered design principles to ensure clarity, intuitive navigation, and accessibility across devices. Formative evaluation involved expert review and qualitative feedback. Content validity was assessed by BT&CLS subject-matter experts, while media and design quality were evaluated by multimedia and instructional design experts using structured questionnaires. Quantitative feasibility scores and qualitative comments guided application revisions. A focus group discussion with instructors, nurses, and an IT expert provided additional insights into content relevance, usability, and implementation. The final phase consisted of quantitative evaluation among 31 BT&CLS trainees. Usability was measured using an adapted System Usability Scale, and technology acceptance was assessed using a modified Technology Acceptance Model questionnaire. Both instruments demonstrated excellent reliability, supporting the robustness of the findings.

Quantitative data were analyzed using descriptive statistics, including mean scores and percentage distributions. SUS scores were calculated according to standard scoring procedures to determine overall system usability. TAM data were analyzed by computing mean values for each construct to describe users' acceptance levels. Qualitative data from expert comments and FGD were analyzed thematically and integrated with quantitative findings to inform conclusions regarding the application's validity, feasibility, and readiness for implementation.

This study was conducted in accordance with ethical principles for research involving human participants and received approval from the Institutional Review Board of the Institute of Technology and Health Bali (Approval No. 04.172/KEPITEKES-BALI/VI/2025). All participants were informed of the study objectives and procedures and provided written informed consent prior to participation. Confidentiality and anonymity were ensured, with no personally identifiable information collected. Data were used solely for research purposes and stored securely in accordance with institutional data protection guidelines. The study followed a modified instructional design-oriented research and development framework, including needs analysis, prototype development, and formative usability evaluation. Quantitative data were analyzed using statistical software to assess instrument reliability and descriptive outcomes related to usability and technology acceptance.

3. RESULTS AND DISCUSSION

This section presents the results of data analysis and expert validation, followed by an integrated discussion that interprets the findings in relation to the study objectives, existing theories, and prior research on digital learning in emergency medical education.

Table 1. Internal Consistency of Instruments for the Development of a Web-Based ECG Learning Application: Usability, Functionality, and Technology Acceptance Aspects

Category	Cronbach's Alpha
Usability	0.979
Functionality	0.979
Portability	0.979

Category	Cronbach's Alpha
Validity	0.979
Reliability	0.980
User Perspective	0.980
Ease of Use (Total)	0.980
Perceived Usefulness (PU)	0.768
Perceived Ease of Use (PEOU)	0.765
Attitude Toward Use (ATU)	0.762
Behavioral Intention to Use (BI)	0.768
Trust, Reliability, and Acceptance	0.768
Technology Acceptance (Total)	0.980

The findings demonstrate that the adapted System Usability Scale (SUS) and modified Technology Acceptance Model (TAM) instruments showed excellent internal consistency, confirming their reliability for evaluating a web-based ECG learning application within BT&CLS training. Cronbach's alpha values exceeding recommended thresholds indicate that items within each construct consistently measured usability and acceptance dimensions, supporting the psychometric robustness of the adapted instruments. These results are consistent with prior evidence showing that SUS and TAM are reliable frameworks for evaluating digital health and educational technologies when appropriately contextualized (Cheah et al., 2023; Lewis, 2018). The exceptionally high reliability across usability-related domains usability, functionality, portability, validity, and reliability suggests that users perceived the application as technically coherent and operationally stable. This consistency is particularly important in emergency education, where learning tools must function intuitively under time pressure and cognitive load. High usability reliability may reduce extraneous cognitive burden and promote learner engagement, thereby facilitating more effective ECG skill acquisition (Köhler et al., 2025; Urstad et al., 2021). Similarly, the strong internal consistency of the overall technology acceptance construct indicates that perceived usefulness, ease of use, attitude, behavioral intention, and trust were cohesively experienced. This supports the core assumptions of TAM that these constructs are interrelated and collectively influence technology adoption. In the BT&CLS context, high acceptance suggests a greater likelihood of sustained use beyond formal training sessions (Lee et al., 2025; Mastour et al., 2025). The reliability of acceptance constructs also reflects the application's relevance to users' clinical and educational needs. ECG interpretation is a critical competency in emergency and life support care, and digital tools perceived as useful and trustworthy are more likely to be integrated into practice. This aligns with evidence that interactive ECG learning tools enhance learner confidence and perceived competence (Lee et al., 2024; Viljoen et al., 2020). Overall, these findings highlight the importance of prioritizing usability and acceptance alongside learning outcomes. The strong psychometric performance of the adapted SUS and TAM supports their reuse in future evaluations and underscores the potential of user-centered web-based ECG learning tools to support sustainable implementation in emergency care education (Sanjana et al., 2025; Siebert et al., 2022).

Table 2. Demographic Characteristics of Emergency Ambulance Training (AGD 118) Participants.

Respondent Characteristics	N	%
Age		
20–30 years	7	22.6
31–40 years	10	32.3
41–50 years	14	45.2

Respondent Characteristics	N	%
Gender		
Male	6	19.4
Female	25	80.6
Education Level		
Diploma (D3)	17	54.8
Bachelor's Degree (S1)	7	22.6
Professional Nurse (Ners)	6	19.4
Master's Degree (S2)	1	3.2
BT&CLS Training Experience		
Never attended	1	3.2
Once	12	38.7
More than once	18	58.1

The demographic profile of participants in this study reflects experienced adult learners rather than novice trainees, with most respondents being middle-aged nurses who had attended BT&CLS training more than once. This is an important contextual factor, as adult learners typically demonstrate goal-oriented learning behaviors and place high value on relevance, efficiency, and usability in educational tools. Positive usability and acceptance findings in this population therefore suggest that the web-based ECG application aligns well with the expectations and practical needs of clinically experienced learners (Viberg et al., 2024). The predominance of female participants and diploma-prepared nurses further reflects the real-world composition of the nursing workforce in emergency and life support settings. As nurses in these roles are frequently required to apply ECG interpretation skills under time pressure, tools that are perceived as intuitive and useful are more likely to be integrated into routine learning and practice. Similar findings have been reported in prior usability studies of digital health applications, where positive user perceptions among practicing nurses were associated with higher acceptance and sustained engagement (Agustini et al., 2025). Repeated exposure to BT&CLS training among more than half of the participants also strengthens the interpretability of the findings. Participants with prior training experience are well positioned to compare traditional instructional approaches with digital learning innovations. Their positive evaluation suggests that the application offers added value beyond conventional training methods, particularly in supporting flexibility and self-directed learning. This aligns with evidence that experienced healthcare professionals are more receptive to educational technologies that clearly enhance efficiency and clinical relevance (Lee et al., 2025). Overall, the demographic characteristics of the study sample enhance the practical relevance of the findings. Demonstrated usability and acceptance among experienced BT&CLS trainees indicate that the application has strong potential for real-world implementation in emergency care education. These results support the broader view that user-centered digital learning tools, when aligned with adult learning principles, can effectively complement established life support training programs (Car et al., 2022).

Table 3. Agreement on the Usability of the Web-Based ECG Learning Application.

Item	Mean	Scale Variance	Item–Total Correlation	Cronbach's Alpha
The application is easy to use without assistance from others	89.77	126.18	0.78	0.97
The menu layout and navigation of the application are clear and well-structured	89.70	126.61	0.79	0.97

Item	Mean	Scale Variance	Item–Total Correlation	Cronbach's Alpha
I can complete ECG tasks/exercises quickly using this application	89.77	125.04	0.79	0.97
I feel comfortable using the application for an extended period	89.74	124.86	0.79	0.97
The features needed to learn ECG are available and easy to access	89.74	125.93	0.71	0.98
All features in the application function as described	89.70	127.21	0.66	0.98
The input process (e.g., entering answers for exercises) runs smoothly without errors	89.83	127.07	0.68	0.98
The application supports all BT&CLS learning needs	89.74	125.93	0.71	0.98
The application can be used on various devices (smartphones, tablets, etc.)	89.64	125.10	0.89	0.97
The application functions well across different operating systems	89.70	123.88	0.92	0.97
Application installation and updates run smoothly	89.67	123.82	0.91	0.97
The ECG materials presented comply with BT&CLS training standards	89.70	127.01	0.68	0.98
The questions or exercises reflect the competencies that must be mastered	89.67	125.15	0.74	0.98
The evaluation/assessment results provided by the application reflect my actual ability	89.74	124.13	0.77	0.98
The application rarely experiences errors during use	89.80	121.96	0.89	0.97
The application is stable and does not crash easily	89.77	122.58	0.90	0.97
My data are stored securely and not lost	89.74	122.33	0.90	0.97
I am satisfied with my experience using this application	89.64	122.90	0.89	0.97
I consider this application important for supporting BT&CLS training	89.67	123.09	0.89	0.97
I am willing to use this application again in the future	89.70	121.68	0.93	0.97

Item	Mean	Scale Variance	Item–Total Correlation	Cronbach's Alpha
I would recommend this application to others	89.74	122.59	0.88	0.97
I will continue to use this application if it is available in the future	89.70	121.68	0.93	0.97

The usability evaluation demonstrated excellent psychometric properties, with a Cronbach's alpha of 0.980 and strong item total correlations across all indicators, confirming that the instrument reliably captured a coherent usability construct. Such high internal consistency aligns with established benchmarks for usability assessment tools, indicating that the application's interface, navigation, and functional components operate in a unified and dependable manner (Cheah et al., 2023; Lewis, 2018). These findings suggest that users experienced minimal confusion or inconsistency when interacting with the system, an essential prerequisite for effective technology-supported learning in healthcare contexts. Participants' strong agreement regarding ease of independent use, clarity of navigation, and efficiency in completing ECG learning tasks indicates high learnability and operational efficiency. From a cognitive perspective, intuitive system design reduces extraneous cognitive load, allowing learners to allocate more mental resources to clinical reasoning and ECG pattern recognition rather than interface management. This supports prior evidence that well-designed digital learning environments enhance engagement and skill acquisition by removing usability barriers (Car et al., 2022; Mahdavi Ardestani et al., 2023). System stability, cross-device compatibility, and data security also received high ratings, highlighting the application's technical robustness and trustworthiness. These attributes are increasingly critical in digital health education, where learners access platforms across multiple devices and environments. Concerns regarding system reliability and data protection have been shown to influence users' willingness to adopt and consistently use educational technologies, particularly in clinical and professional settings (Siebert et al., 2021; Viberg et al., 2024). The present findings suggest that the application meets these expectations, thereby supporting sustained user engagement. Importantly, indicators related to learning relevance such as alignment with BT&CLS standards and the perceived realism of evaluation results were rated highly, underscoring the application's educational validity. ECG interpretation is a core competency linked directly to timely clinical decision-making, especially in acute coronary syndromes where delays can adversely affect patient outcomes (Byrne et al., 2023; Lin et al., 2023). By aligning learning content with recognized standards, the application enhances its relevance to real-world clinical practice and reinforces the transferability of acquired skills.

High usability may also contribute to addressing persistent gaps in ECG interpretation competency among nurses and other healthcare professionals. Previous studies have reported variable and often suboptimal ECG interpretation skills, frequently attributed to limited training opportunities and ineffective educational approaches (Chen et al., 2025; Rahimpour et al., 2021). A user-friendly, accessible digital application may help mitigate these challenges by enabling repeated practice, self-directed learning, and timely feedback without the constraints of traditional classroom-based instruction. The findings further align with evidence supporting technology-enhanced and blended learning approaches for ECG education. Digital and web-based ECG learning tools have been shown to be as effective as, or superior to, conventional lectures in improving interpretation accuracy and learner confidence, particularly when usability is high (Lee et al., 2024; Viljoen et al., 2020). In this context, the strong usability performance of the application likely acts as an enabling factor that maximizes the pedagogical benefits of digital ECG instruction. Overall, the results indicate that the application successfully integrates sound usability principles with educational relevance, creating a learning

environment that supports effective ECG skill development. Consistent with prior mobile health and educational app development studies, high usability appears to be a foundational requirement for achieving meaningful learning outcomes and user acceptance (Agustini et al., 2022; Urstad et al., 2021). These findings reinforce the importance of prioritizing usability alongside content accuracy in the design of digital learning tools for healthcare education.

Table 4. Agreement on Technology Acceptance of the Web-Based ECG Learning Application.

Item	Mean	Scale Variance	Item–Total Correlation	Cronbach’s Alpha
Perceived Usefulness (PU) – Using the application improves my understanding of ECG	106.80	198.69	0.76	0.76
Perceived Usefulness (PU) – The application increases my speed in learning ECG	106.87	197.44	0.88	0.76
Perceived Usefulness (PU) – The application improves the quality of BT&CLS learning	106.74	195.26	0.94	0.76
Perceived Usefulness (PU) – The application supports independent practice after training	106.77	198.84	0.82	0.76
Perceived Ease of Use (PEOU) – The application is easy to learn how to use	106.96	199.36	0.75	0.76
Perceived Ease of Use (PEOU) – Menu navigation and application features are easy to understand	106.87	197.51	0.79	0.76
Perceived Ease of Use (PEOU) – I can use the application without much assistance from others	106.87	196.98	0.82	0.76
Attitude Toward Using (ATU) – I enjoy using this application	106.77	194.31	0.93	0.76
Attitude Toward Using (ATU) – I believe this application is important for BT&CLS training	106.70	195.61	0.91	0.76
Behavioral Intention to Use (BI) – I intend to continue using this application in the future	106.80	193.62	0.91	0.76
Behavioral Intention to Use (BI) – I would recommend this application to colleagues	106.90	189.29	0.90	0.75
Trust – I am confident that my data and practice results are securely stored	106.77	193.18	0.92	0.75

Trust – I believe the application provides accurate information	106.83	195.47	0.89	0.76
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The Technology Acceptance Model (TAM) analysis demonstrated strong and consistent acceptance across all constructs, supported by high item correlations and satisfactory internal reliability. Cronbach's alpha values within the acceptable range indicate that perceived usefulness, perceived ease of use, attitude, behavioral intention, and trust were measured reliably, reinforcing the robustness of the acceptance framework applied in this study. High perceived usefulness suggests that learners recognized the application as a meaningful tool for improving ECG comprehension, accelerating the learning process, and enhancing the overall quality of BT&CLS training, which is central to sustained technology adoption in educational settings (Lee et al., 2025). Perceived ease of use emerged as a key facilitator of acceptance, particularly in relation to intuitive navigation and the ability to learn independently without external assistance. Within TAM, ease of use not only directly influences behavioral intention but also indirectly enhances perceived usefulness by lowering cognitive and operational barriers. The present findings support this theoretical pathway, as positive usability perceptions were accompanied by favorable attitudes and strong intentions to reuse and recommend the application. This pattern is consistent with empirical extensions of TAM in health professions education, where learner autonomy and system simplicity have been shown to be critical determinants of engagement and continued use (Mastour et al., 2025). Notably, trust-related constructs further strengthened technology acceptance in this study. Participants' confidence in data security and information accuracy appeared to reinforce positive attitudes and behavioral intentions, highlighting trust as a complementary determinant within digital health education environments. As learning platforms increasingly store performance records and learner data, trust becomes a salient factor that shapes acceptance beyond traditional TAM variables (Johnson et al., 2022). This finding extends the core TAM framework by emphasizing that trust functions as a reinforcing mechanism, particularly in healthcare-related educational technologies where data sensitivity and content credibility are paramount (Lee et al., 2025).

Expert Validation: Content Quality

Content expert validation demonstrated a high level of feasibility, with an overall score of 87.04%, indicating that the application's instructional content is appropriate for implementation without major revision. Mean scores exceeding 4.0 across all evaluated dimensions accuracy, curriculum alignment, completeness, clarity, and instructional design suggest that the learning materials meet accepted standards for professional nursing education. Expert confirmation that the ECG content is current and aligned with BT&CLS and American Heart Association guidelines is particularly important, as inaccuracies or outdated information in ECG education may directly affect clinical decision-making and patient safety, especially in time-sensitive cardiac conditions. The structured sequencing of content, progressing from foundational ECG concepts to clinically significant arrhythmias, was identified as a key pedagogical strength. Such scaffolded learning design supports knowledge integration and skill progression, which are essential for developing clinical reasoning in ECG interpretation. This approach aligns with evidence indicating that well-organized and curriculum-aligned digital learning resources enhance learner comprehension and reduce cognitive overload in healthcare education (Mahdavi Ardestani et al., 2023). High ratings for language clarity further indicate that the application successfully balances technical rigor with accessibility for nursing professionals. Clear and concise instructional language is essential for facilitating independent learning and minimizing misinterpretation of complex physiological concepts. Additionally, experts' positive appraisal of adult learning principles confirms that the application effectively supports self-directed, goal-oriented learning through modular content, interactive quizzes, and

timely feedback. These design features are known to reinforce knowledge retention and learner motivation, thereby strengthening the educational value of digital training tools in professional contexts (Ryan et al., 2024).

Expert Validation: Media and Usability Aspects

The high feasibility scores (>85%) reported by media and design experts indicate that the application demonstrates strong usability, visual coherence, multimedia integration, and technical stability. These findings suggest that the application has reached a level of design maturity that supports consistent and reliable use across different devices and learning contexts. In digital health education, such design quality is essential because poorly optimized interfaces can disrupt learning flow and reduce engagement, even when instructional content is strong. The clean and intuitive interface described by experts reflects successful implementation of user-centered design principles, which emphasize alignment between system functionality and user needs (Köhler et al., 2025). The application's responsiveness across devices further supports flexible access for both formal BT&CLS training and independent, self-paced study. This flexibility is particularly relevant in nursing and clinical education, where learners often balance training with demanding clinical schedules. Prior studies in nursing education have shown that accessible and well-designed digital platforms enhance perceived value and sustained use by accommodating varied learning environments and time constraints (Urstad et al., 2021). Thus, the current design quality may contribute not only to positive user experience but also to consistent learning engagement. Experts' observations that the design facilitates engagement without overwhelming users indicate an appropriate balance between visual stimulation and cognitive simplicity. Avoiding excessive animations or interface complexity helps prevent unnecessary cognitive load, allowing learners to focus on ECG interpretation rather than navigating the system. This finding aligns with earlier mobile health application development studies, which emphasize that simplicity and clarity are central determinants of usability and functional effectiveness in healthcare learning tools (Agustini et al., 2025). Importantly, expert suggestions focused on future enhancements such as incorporating additional animations or advanced case simulations rather than identifying critical design flaws. This type of developmental feedback suggests that the foundational design is already sound and suitable for implementation, with further refinements aimed at expanding instructional depth rather than correcting usability deficiencies. Such feedback is characteristic of well-developed educational applications that are ready for iterative improvement and scaling, rather than fundamental redesign (Agustini et al., 2022).

Focus Group Discussion: User Perspectives

Findings from the focus group discussions reinforced and contextualized the quantitative results, providing deeper insight into how the application functions within real learning environments. Participants consistently perceived the content as relevant, accurate, and well aligned with BT&CLS training needs, particularly for strengthening ECG interpretation skills before and after formal instructional sessions. This perceived relevance is critical, as prior research has identified gaps in ECG competency among nurses and emphasized the need for accessible reinforcement tools to support ongoing skill development beyond classroom instruction (Chen et al., 2025; Rahimpour et al., 2021). Participants highlighted comprehensive content coverage, intuitive navigation, and interactive features as key strengths, suggesting that the application effectively supports active and self-directed learning. Such features are known to enhance learner engagement and facilitate repeated practice, which is essential for mastering complex perceptual skills such as ECG interpretation. Digital ECG education studies have demonstrated that interactive and practice-oriented learning environments can significantly improve interpretation accuracy compared to passive instructional approaches (Kashou et al., 2024; Krasne et al., 2021). Suggestions for improvement such as expanding advanced

arrhythmia cases, enhancing waveform contrast, and introducing timed practice modes reflect learners' desire for greater clinical realism and performance pressure. These recommendations are particularly relevant given that ECG interpretation in emergency settings often occurs under time constraints and high cognitive load. Incorporating simulation-like features and advanced case complexity may further strengthen the application's capacity to prepare learners for real-world clinical decision-making, aligning with evidence that authentic task design enhances transfer of learning to practice (Flores-Martin et al., 2025; Lin et al., 2023). The emphasis on maintaining up-to-date guidelines further underscores participants' awareness of the patient safety implications associated with ECG interpretation. In acute cardiac care, adherence to current evidence-based guidelines is essential, as outdated knowledge may contribute to delayed or inappropriate clinical responses. This feedback highlights the importance of continuous content updating in digital learning tools to ensure alignment with evolving clinical standards (Byrne et al., 2023; Wang et al., 2023). Overall, the FGD findings emphasize the value of integrating end-user feedback into the iterative development of educational technologies. Participants' endorsement of a blended learning approach combining instructor-led sessions with digital self-learning tools supports contemporary models of medical education that view technology as a complement rather than a replacement for traditional teaching. Such integration has been shown to enhance learning flexibility, reinforce knowledge retention, and accommodate diverse learning preferences in health professions education (Lee et al., 2024; Tudor Car et al., 2022).

Integrated Discussion and Theoretical Implications

Collectively, the findings demonstrate that the web-based ECG learning application is usable, acceptable, and pedagogically robust for BT&CLS training. The convergence of content expert validation, media and design evaluation, usability testing, and user acceptance analysis indicates a coherent and methodologically sound development process. Such triangulation strengthens internal validity and suggests that the application meets both educational and technological quality standards required for clinical training environments. Similar multimethod evaluation strategies have been recommended as best practice in digital health education to ensure functional reliability and instructional effectiveness (Car et al., 2022; McGee et al., 2024). From a theoretical standpoint, the results strongly support the Technology Acceptance Model (TAM) within the context of emergency and nursing education. High perceived usefulness and ease of use translated into positive attitudes and strong behavioral intention, consistent with TAM propositions across health professions education. Importantly, the findings also highlight the reinforcing role of trust particularly related to data security and content accuracy suggesting an extension of classical TAM when applied to clinical learning technologies. This aligns with recent systematic and empirical studies emphasizing trust as a critical determinant of acceptance in medical education technologies (Lee et al., 2025; Mastour et al., 2025). Usability outcomes further reinforce usability theory, indicating that intuitive navigation, visual clarity, and system responsiveness are essential enablers of learning engagement. High usability scores suggest that learners can focus cognitive resources on ECG interpretation rather than interface management, reducing extraneous cognitive load. Prior studies in nursing and healthcare education have consistently demonstrated that usability is not merely a technical feature but a pedagogical prerequisite for effective digital learning (Lewis, 2018; Urstad et al., 2021). Pedagogically, the application addresses well-documented gaps in ECG competency among nurses and emergency care providers by enabling repeated practice, modular learning, and immediate feedback. This design aligns with adult learning theory, which emphasizes self-directed, goal-oriented learning and timely feedback as key drivers of skill acquisition. Evidence from ECG education research indicates that interactive and adaptive

digital approaches outperform traditional lecture-based or paper-based instruction in developing interpretation accuracy and retention (Kashou et al., 2024; Krasne et al., 2021).

The application's alignment with BT&CLS, American Heart Association, and European clinical guidelines further strengthens its clinical relevance and patient safety implications. Accurate and up-to-date ECG interpretation is critical in acute cardiac care, where delays or misinterpretation can directly affect outcomes. By embedding guideline-consistent content into a readily accessible digital platform, the application supports timely clinical decision-making and reinforces evidence-based practice (Byrne et al., 2023; Soar et al., 2021). The blended learning potential of the application represents another key theoretical and practical contribution. Participants' acceptance of the application as a complement to instructor-led training aligns with contemporary models of medical education that view technology as an enhancer rather than a replacement of face-to-face teaching. Empirical evidence suggests that blended and web-based ECG learning improves performance, flexibility, and learner satisfaction across nursing and medical education settings (Lee et al., 2024; Viljoen et al., 2020). Finally, the strong expert and user endorsement indicates that the application is not only ready for implementation but also suitable for iterative enhancement. Suggestions for advanced simulations and expanded arrhythmia cases reflect learners' readiness for higher-level clinical realism rather than deficiencies in foundational design. This trajectory aligns with digital learning research emphasizing continuous refinement based on user feedback to maximize long-term educational impact (Agustini et al., 2022; Flores-Martin et al., 2025).

4. CONCLUSION

This study developed and validated a web-based ECG learning application for Basic Trauma and Cardiac Life Support (BT & CLS) training. The application demonstrated strong content validity, high usability, and high user acceptance, supported by reliable usability and technology acceptance measures and positive qualitative feedback. These findings indicate that the application is a feasible and user-friendly digital tool that can complement conventional ECG training. Further research is needed to evaluate its impact on learning outcomes and clinical performance in emergency care settings.

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