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Evaluating the Usability of a Marker-Based Augmented Reality Application for Electronics Learning in Secondary Education

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ABSTRACT

The integration of marker-based Augmented Reality (AR) in STEM education has received growing scholarly attention because of its capacity to visualise abstract concepts and facilitate interactive learning. However, many existing AR tools continue to present usability challenges, inconsistencies in interaction design, and limited alignment with learners' cognitive needs. These issues affect their effectiveness in actual classroom contexts. This study evaluates the usability of ElecSAR, a marker-based AR application developed to support secondary school students in learning electronic circuits through interactive 3D visualisation and guided simulation. The development of ElecSAR followed a Design and Development Research approach that included needs analysis, expert validation using the Fuzzy Delphi Method, and iterative prototyping. A usability investigation was conducted with secondary school students (N = 34) through 5 weeks implementation, and evaluated using a questionnaire based on the four constructs of the Technology Acceptance Model (TAM). The findings indicate consistently high user ratings for Perceived Usefulness (M = 4.66, SD = 0.51), Perceived Ease of Use (M = 4.61, SD = 0.48), Attitude Towards Use (M = 4.75, SD = 0.43), and Behavioral Intention (M = 4.68, SD = 0.44). These results are supported by acceptable internal reliability values that range from alpha 0.74 to 0.84. Although the mean scores are high, the narrow score distribution suggests the possible influence of novelty effects, positive response tendencies, or the short exposure to the application. The study provides initial insight into students' perceptions of ElecSAR. However, several limitations remain, including a modest number of participants and a short evaluation duration. Future research should include extended use of the application, and triangulation with performance data and behavioural observations. The study also highlights the importance of user centred and pedagogically grounded design principles in the development of educational AR applications.

1. Introduction

The expansion of electronics and microcontroller education in primary and secondary schools has grown rapidly in recent years, reflecting global efforts to prepare learners for STEM oriented fields that require design thinking, computational reasoning, and problem solving competence. Many national curricula now incorporate microcontroller and circuit related content within STEM and

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technology subjects through tools such as Arduino, Microbit, and visual programming platforms, which support inquiry based and hands on learning [1]–[3]. Despite these developments, students often continue to experience difficulty understanding circuit behaviour, functional relationships between components, and the spatial structure of electronic systems [4] [5]. These challenges have been linked to persistent misconceptions, reduced confidence, and declining engagement in electronics learning at the secondary level.

Digital technologies such as AR have been introduced to mitigate these difficulties by enabling interactive visualisation of electronic processes, supporting exploratory learning, and presenting technical concepts in ways that are not possible through static diagrams or physical components alone [6], [7]. AR allows virtual elements to be registered within the real environment, giving learners the opportunity to observe circuit operations that are normally invisible and to interact with guided simulations [8], [9]. Studies in electronics, robotics, and microcontroller education have reported improvements in motivation, performance, and spatial reasoning among students who used AR-based learning tools [10]–[12]. However, these benefits are not consistently realised in formal classroom settings. Prior research has documented recurring issues related to usability, cognitive overload, technical instability, and variability in user experience, which limit the practical adoption of AR in school environments [13]–[15]. Difficulties with interface navigation, unreliable marker detection, and the demand for high levels of digital preparedness among teachers have further constrained its integration [16] [17], [18].

Given these constraints, the effectiveness of AR in education depends not only on its technical capabilities but also on its usability and alignment with learners' cognitive needs. Although various studies have examined the pedagogical value of AR, fewer investigations have focused specifically on the usability of AR applications for learning electronic circuits in secondary schools. Existing work often emphasises technological innovation rather than the degree to which students can interact with the applications in intuitive and cognitively manageable ways. This gap highlights the need for empirical evidence that examines how learners perceive the usefulness, ease of use, and interaction quality of AR tools designed for electronics learning.

The present study addresses this gap by evaluating the usability of ElecSAR, an AR application developed to support the learning of electronic circuits through interactive visualisation and guided simulation. ElecSAR incorporates structured learning steps, simplified interactions, and stable marker recognition to reduce cognitive load and improve the clarity of circuit-based visualisation. The study investigates students' perceptions of ElecSAR with regard to usefulness, ease of use, attitudes towards the application, and intention to use it in future learning. By focusing on usability rather than performance outcomes, this research provides insights into the design features that support or hinder effective interaction and contributes evidence to guide the development of user-centred AR tools for secondary STEM education.

2. Methodology

This study applied a Design and Development Research approach to design, refine, and evaluate the usability of the ElecSAR marker-based Augmented Reality application for secondary school electronics learning. This approach was appropriate because it supports iterative development, continuous validation, and alignment of educational technologies with real classroom contexts. The research comprised three main phases, namely needs analysis, design and development, and usability evaluation with the target user group.

2.1 Design and Development Research (DDR) Process

The research process followed a three phase Design and Development Research structure, as illustrated in Figure 1.

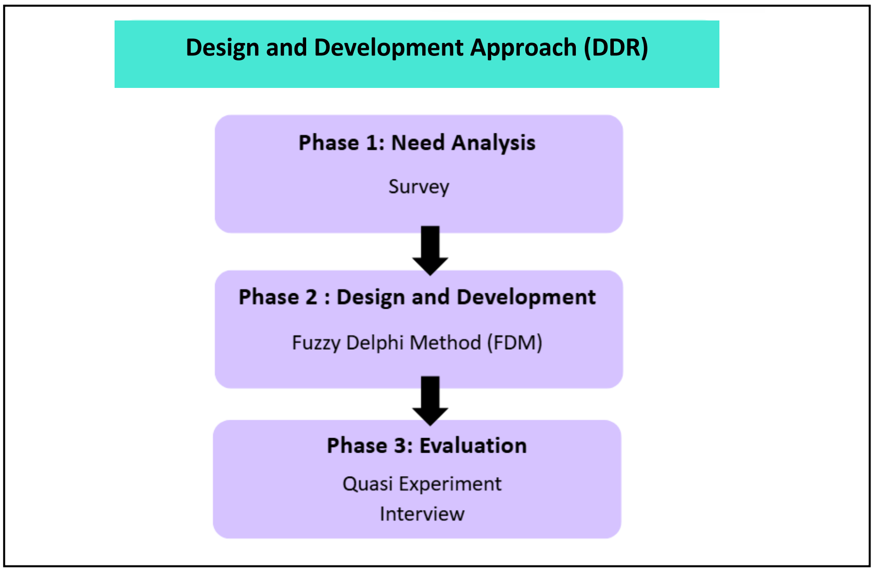

Fig. 1. Research Flowchart of the ElecSAR Development Process [19]

Phase 1 (Needs Analysis): The first phase aimed to identify the pedagogical and technical requirements for an Augmented Reality simulation tool to support the teaching of electronic design within the Design and Technology curriculum. A survey was administered to 329 Form Two teachers to obtain empirical insights into the instructional challenges they encountered, the misconceptions commonly observed among students, and the extent to which teachers perceived a need for an Augmented Reality based learning tool. The findings informed the initial pedagogical and interaction design specifications for ElecSAR and highlighted the gap between curriculum expectations and the resources currently available to teachers.

Phase 2 (Design and Development): The second phase involved expert consultation through the Fuzzy Delphi Method (FDM) with fifteen experts in electronic design, TVET, and educational technology. The experts provided consensus on essential components, interaction features, and pedagogical elements that should be incorporated in an AR tool for electronics learning. These validated elements guided the structural and functional design of ElecSAR. A prototype was then developed using OpenSpace3D and Blender, incorporating marker-based Augmented Reality to support 3D visualisation and guided simulation. The prototype underwent internal review by seven experts for validation to identify usability issues interaction inconsistencies that might hinder classroom application. Figures 2 to 5 illustrate selected simulation screens and visualisation features within the ElecSAR application.

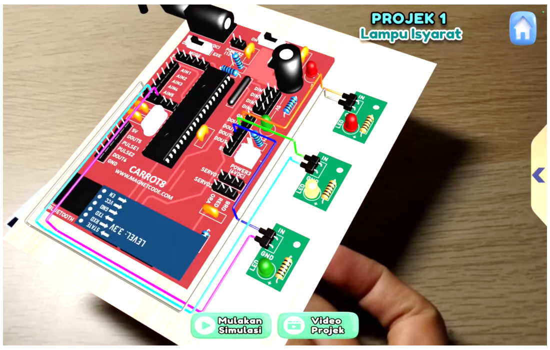

Fig. 2. Traffic Light System using LED using LED sequence control

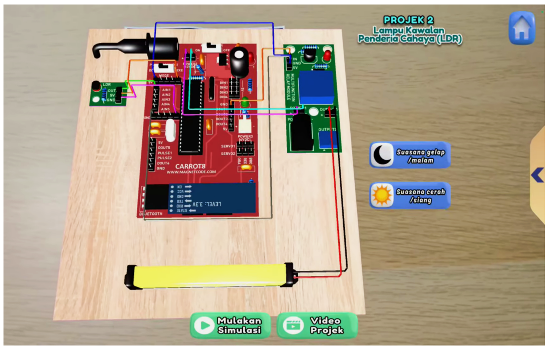

Fig. 3. Automatic Lamp controlled by light-dependent resistor (LDR)

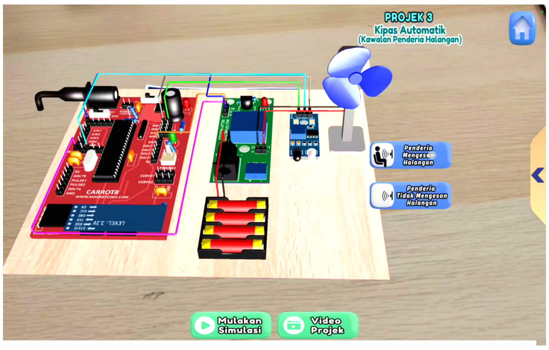

Fig. 4. Automatic Fan controlled by infrared (IR) sensor

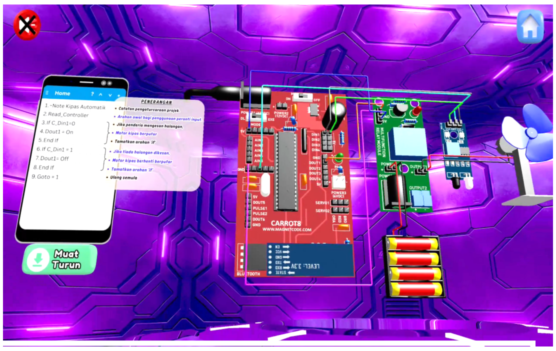

Fig. 5. Virtual Reality (VR) tutorial in ElecSAR

Phase 3 (Evaluation): The third phase focused on evaluating the usability of ElecSAR through student testing conducted in an authentic classroom environment. The usability evaluation examined students' perceptions of the usefulness, ease of use, attitudes toward the application, and their intention to use similar tools in future learning. This phase provided insight into the degree to which the design decisions made in earlier phases aligned with the cognitive demands and learning needs of actual users.

Fig. 6. Students interacting with the AR simulation features in the ElecSAR application

2.2 Sampling Procedure and Study Implementation

A total of 68 Form Two students from two public secondary schools participated in the study. Cluster sampling was used, with intact classrooms selected as the sampling units. The students were assigned to a control group and a treatment group, with 34 students in each group. All participants had no prior exposure to electronic circuit topics, ensuring that the intervention took place before any formal instruction in the relevant learning standards. The implementation was conducted across five weeks and covered eight learning standards (learning standard 2.4.1 to 2.4.8), which included electronic components, circuit principles, sensing devices, and introductory electronic projects. During this period, the treatment group used ElecSAR during structured learning sessions involving visualisation, simulation, and guided exploration activities, while the control group continued with conventional instruction. This paper reports the usability evaluation findings obtained from the treatment group at the end of the five weeks implementation.

3. Results

Students' perceptions of the ElecSAR application were assessed using a structured questionnaire adapted from the Technology Acceptance Model. The instrument comprised four constructs, namely perceived usefulness, perceived ease of use, attitudes toward use, and behavioural intention to use. Data were obtained from thirty four students who had used ElecSAR during classroom instruction. Table 1 presents the reliability statistics for each construct. The Cronbach alpha values ranged from 0.74 to 0.84, indicating acceptable internal consistency. Perceived usefulness demonstrated the highest reliability (α = 0.84), followed by attitude towards use (α = 0.81), behavioural intention (α = 0.80), and perceived ease of use (α = 0.74).

Table 1
Reliability of Constructs

Construct	Number of Items	Cronbach's Alpha
Perceived Usefullness (PU)	5	0.84
Perceived Ease of Use (PEU)	6	0.74
Attitude Towards Use (AT)	5	0.81
Behavioral Intention to Use (BI)	4	0.80

The reliability values suggest that the instrument captured students' perceptions consistently across all constructs, supporting its suitability for examining acceptance of the ElecSAR application.

3.1.1 Perceived Usefullness (PU)

Table 2 summarises students' responses for the perceived usefulness construct. The overall mean score was 4.66 (SD = 0.51), indicating that students generally viewed the application as beneficial for learning electronic design. The item "The application helps me improve my circuit connection skills" received the highest mean (M = 4.78, SD = 0.42). Students also agreed that the application was useful for learning the topic (M = 4.75, SD = 0.44) and that it supported their mastery of electronic design concepts (M = 4.66, SD = 0.48). The lowest score in the construct, "The application makes it easier for me to understand lesson content," was still within the high range (M = 4.43, SD = 0.72). The relatively small standard deviations across items demonstrate a high degree of agreement among respondents. These findings suggest that students experienced the application as a supportive tool for understanding both conceptual and procedural aspects of electronic design.

Table 2
Students' Perception Survey Result on Perceived Usefulness (PU)

No.	Item	Mean	SD
1	The ElecSAR application helps me to master the topic of Electronic Design.	4.66	0.48
2	The ElecSAR application makes my learning more productive and effective.	4.66	0.48
3	The ElecSAR application makes it easier for me to understand the content of Electronic Design lessons.	4.43	0.72
4	The ElecSAR application helps me improve my circuit connection skills.	4.78	0.42
5	I find the ElecSAR application very useful for learning Electronic Design.	4.75	0.44
	Average	4.66	0.51

3.1.2 Perceived Ease of Use (PEU)

The Perceived Ease of Use (PEU) construct presented in Table 3 reveals important information regarding service quality. The (Mean = 4.61; SD = 0.48), data confirmed ElecSAR application is easy to use based on statement "ElecSAR easy to use" The mean value for the item was highest for "I find the ElecSAR application easy to use" (M = 4.75, SD = 0.44). Second highest was "I can become skilled at using the ElecSAR application easily" (M = 4.72, SD = 0.46) and next in line was "It is easy for me to learn how to use the ElecSAR application" (M = 4.66, SD = 0.48). The interface clarity and interaction are rated highly. Items such as "The interaction within the ElecSAR application is clear" (M = 4.50, SD = 0.51) and "The interaction within the ElecSAR application is easy to understand" (M = 4.41, SD = 0.50) scored well. Students also agreed that information can be easily accessible through the application (M = 4.59, SD = 0.50). The small variation in the values of standard deviation indicates that the students all gave almost similar responses. These findings support the conclusion that ElecSAR is easy to use and accessible, and helps students feel more confident while learning with it.

Table 3
Students' Perception Survey Result on Perceived Ease of Use (PEU)

No.	Item	Mean	SD
1	I find the ElecSAR application easy to use	4.75	0.44
2	Learning how to use the ElecSAR application is easy for me	4.66	0.48
3	I can become skilled at using the ElecSAR application easily	4.72	0.46
4	The interaction within the ElecSAR application is clear	4.50	0.51
5	The interaction within the ElecSAR application is easy to understand	4.41	0.50
6	I can obtain information easily through the ElecSAR application	4.59	0.50
	Average	4.61	0.48

3.1.3 Attitude Towards Use (AT)

Table 4 presents the findings for attitude towards use. The construct recorded an overall mean of 4.75 (SD = 0.43), demonstrating positive attitudes toward the application. The item "I support the use of the application for learning purposes" yielded the highest mean (M = 4.88, SD = 0.34). Students also indicated that the application encouraged their active involvement in learning (M = 4.78, SD = 0.42). Other items, such as perceiving learning with the application as beneficial (M = 4.75, SD = 0.44) and maintaining a positive attitude toward its use (M = 4.69, SD = 0.47), also

reflected strong agreement. Although "Learning using the application is the best approach" received the lowest mean in this construct (M = 4.66, SD = 0.48), it remained within the high range.
The consistently low standard deviations indicate shared perceptions among students. The pattern of responses suggests that the application was perceived positively and integrated well into the learning experience.

Table 4
Students' Perception Survey Result on Attitude Towards Use (AT)

No.	Item	Mean	SD
1	Learning using the ElecSAR application is the best approach	4.66	0.48
2	I have a positive attitude towards using the ElecSAR application	4.69	0.47
3	I believe that the ElecSAR application helps me to engage actively in learning	4.78	0.42
4	I support the use of the ElecSAR application for learning purposes	4.88	0.34
5	Using the ElecSAR application in learning sessions will benefit me	4.75	0.44
	Average	4.75	0.43

3.1.4 Behavioral Intention to Use (BI)

Behavioural intention to use the application yielded an overall mean of 4.68 (SD = 0.44), as shown in Table 5. Two items recorded the highest means (M = 4.84, SD = 0.37): the intention to use the application during learning sessions and the intention to use it comprehensively. Students also expressed an intention to continue using the application throughout the electronic design topic (M = 4.56, SD = 0.50). The lowest scoring item, "I intend to use the application repeatedly as often as possible," still registered a high agreement level (M = 4.47, SD = 0.51). Standard deviations across items were small, indicating consistency of responses. The consistently high means must be interpreted cautiously, as short term exposure and novelty effects may influence intention ratings. Nonetheless, the pattern suggests that students were receptive to the idea of using such technologies as part of their learning.

Table 5
Students' Perception Survey Result on Behavioral Intention to Use (BI)

No.	Item	Mean	SD
1	I intend to use the ElecSAR application during learning sessions	4.84	0.37
2	I intend to use the ElecSAR application comprehensively	4.84	0.37
3	I intend to continue using the ElecSAR application throughout the Electronic Design learning process	4.56	0.50
4	I intend to use the ElecSAR application repeatedly as often as possible	4.47	0.51
	Average	4.68	0.44

4. Discussion

The findings of this study provide insight into how secondary school students perceived the ElecSAR application after several weeks of classroom use. The consistently high ratings across the four constructs of the Technology Acceptance Model suggest that students generally regarded the application as useful, manageable to operate, and supportive of their learning engagement. These perceptions align with earlier studies showing that Augmented Reality can facilitate conceptualisation by enabling learners to observe relationships, behaviours, and spatial structures that are not easily accessible through conventional instruction. The application's visualisation and simulation features appear to have supported students in making sense of circuit behaviour and component interactions, which corresponds with previous research demonstrating that interactive Augmented Reality environments can scaffold understanding in electronics and related STEM domains.

Students also reported favourable attitudes toward using the application and expressed an intention to use similar tools in future lessons. These trends are consistent with theoretical expectations of the Technology Acceptance Model, in which perceptions of usefulness and ease of use influence attitudes and behavioural intention. The observed pattern may reflect the structured design of the application, which emphasised clear interactions, accessible visual cues and a guided sequence for exploring electronic circuits. These design elements were informed by the earlier needs analysis and expert validation process, suggesting that the iterative development stages contributed to producing an interface that was perceived as intelligible and supportive for novice learners.

Although the responses were strongly positive, several considerations temper the interpretation of these findings. The very high means and the narrow distribution of scores, while indicating consensus, may also be influenced by contextual factors such as the novelty of using Augmented Reality in class, the short duration of exposure and students' enthusiasm for new technologies. Similar patterns have been noted in previous educational technology studies where early adoption phases can generate inflated ratings due to curiosity or social desirability. As the evaluation relied exclusively on self-reported measures, it is not possible to determine the extent to which these perceptions would remain stable during extended use or under varying instructional conditions.

Another point to note is that the findings pertain only to students in the treatment group and do not include comparative usability perceptions from students who learned through conventional instruction. Furthermore, while the data provide insight into perceived usefulness and ease of use, they do not directly assess learning performance, cognitive load or behavioural engagement. Therefore, the results primarily reflect subjective impressions of usability rather than the broader effectiveness of the application in supporting learning outcomes.

Taken together, the findings suggest that an Augmented Reality application developed with attention to clarity, interaction simplicity, and cognitive accessibility can be well received by secondary school learners in electronics education. However, the broader implications of these findings must be approached cautiously. More comprehensive investigations are needed to examine how such applications perform when integrated across longer instructional sequences, when used by different learner groups and when evaluated alongside objective learning measures. Future work should also explore how specific design features influence user experience to refine the development of Augmented Reality tools that are both pedagogically grounded and usable in diverse classroom environments.

5. Conclusions

A marker-based Augmented Reality application, ElecSAR, was developed to assist secondary school students in constructing simple electronic circuits. Based on the results, participants reported extremely high scores in perceived usefulness, perceived ease of use, attitude and behavioural intention which indicates that students found ElecSAR to be helpful, easy and fun to use in the classroom. The results show that ElecSAR's clear visualisation, stable marker tracking, and stepwise AR simulation supported students with no prior electronics knowledge and allowed them to comfortably explore circuit concepts. In general, the usability evidence indicates that ElecSAR has good potential to be a practical and effective AR tool for electronics lessons, and further work may investigate its effects on learning outcomes and long-term usage in STEM education.

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