The Effectiveness of FLASHDuino - A Revolution in Active Learning Through Flashcards, Digital Simulation, AI, and Arduino Kits

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Abstract

The rapid advancement of Industry 4.0 technologies has increased the demand for innovative teaching approaches that integrate digital tools, active learning, and practical skill development in Technical and Vocational Education and Training (TVET). However, many students encounter difficulties in understanding electronic circuit design, Arduino programming, and the relationship between theoretical concepts and practical implementation. To address these challenges, FLASHDuino was developed as an integrated learning innovation that combines flashcards, Tinkercad digital simulation, ChatGPT-assisted Arduino programming, and project-based learning activities. This study aimed to develop and evaluate the effectiveness of FLASHDuino in enhancing students' understanding of electronic circuit assembly and Arduino programming, as well as to determine students' motivation and engagement levels when using the innovation. A quantitative descriptive research design was employed. The study involved 92 students enrolled in the Certificate of Electrical Technology Programme at Sandakan Community College. Data were collected using a structured questionnaire comprising three dimensions: student motivation, engagement, and perceived learning effectiveness. Descriptive statistical analysis involving mean scores and standard deviations was conducted. The findings revealed very high levels of student motivation (M = 4.83, SD = 0.38), engagement (M = 4.80, SD = 0.40), and perceived learning effectiveness (M = 4.84, SD = 0.37). Students reported that FLASHDuino enhanced their understanding of electronic circuits and Arduino programming, improved problem-solving abilities, encouraged independent learning, and strengthened the connection between theory and practical application. The integration of flashcards, simulation, artificial intelligence, and hands-on project implementation also contributed to a more interactive and meaningful learning experience. In conclusion, FLASHDuino demonstrates strong potential as an innovative teaching and learning tool for electronics education in TVET institutions. The findings suggest that integrating digital simulation, artificial intelligence, and project-based learning can effectively enhance student engagement, motivation, and practical competency development.

Keywords: Active Learning; Arduino Programming; Artificial Intelligence; Digital Simulation; FLASHDuino.

1.0 Introduction

Technical and Vocational Education and Training (TVET) play an essential role in preparing graduates with the knowledge, technical competencies, and employability skills required by modern industries. In electronics education,

students are expected not only to understand theoretical concepts but also to demonstrate practical competencies in circuit assembly, troubleshooting, programming, and system integration. Consequently, teaching and learning approaches should provide opportunities for students to apply theoretical knowledge through authentic and meaningful practical experiences (Azid et al., 2023).

However, many students experience difficulties when learning electronics because circuit diagrams, programming logic, and component interactions are often abstract and difficult to visualise. While students may understand theoretical explanations delivered during lectures, they frequently struggle to transfer this knowledge into practical applications. This challenge becomes more apparent when students are required to construct electronic circuits and develop Arduino-based projects independently.

The increasing adoption of Industry 4.0 technologies has also transformed expectations regarding technical education. Today's graduates are expected to possess digital literacy, problem-solving abilities, critical thinking skills, creativity, and the ability to utilise emerging technologies effectively. As a result, educators are encouraged to adopt innovative teaching approaches that promote active learning, self-directed learning, and technology-enhanced learning experiences (Abramenka-Lachheb & Ozogul, 2022).

Recent studies have shown that simulation-based learning environments can improve students' understanding of technical concepts by allowing them to experiment and troubleshoot within a safe and interactive environment before implementing projects physically (Juera, 2022). Similarly, project-based learning using Arduino platforms has been recognised as an effective approach for strengthening practical competencies, creativity, and innovation among engineering and electronics students (Zadorozhnii, 2024).

The emergence of artificial intelligence (AI) tools such as ChatGPT has also created new opportunities for learning. AI-assisted learning can support students by providing immediate guidance, explanations, and programming assistance, enabling learners to explore concepts independently and develop greater confidence in problem-solving activities (Pedraja-Rejas et al., 2024).

Recognising these educational opportunities, FLASHDuino was developed as a flashcard-based learning innovation that integrates Tinkercad simulation, ChatGPT-assisted Arduino programming, and physical Arduino project development. Through a structured learning workflow, students first study circuit diagrams using FLASHDuino flashcards, construct circuits digitally using Tinkercad, generate Arduino code with the assistance of ChatGPT, test the project through simulation, and finally implement the project physically using actual electronic components and Arduino boards. This integrated

approach aims to enhance students' understanding, engagement, confidence, and practical competencies in electronics learning.

One of the major challenges in electronics education is helping students understand the relationship between circuit diagrams, programming logic, and physical implementation. Although students are often able to memorise theoretical concepts, many encounter difficulties when required to translate these concepts into functioning electronic systems.

Preliminary observations conducted during electronics practical sessions at Sandakan Community College revealed that students frequently required extensive lecturer guidance when assembling circuits and developing Arduino-based projects. Many students struggled to identify correct component connections, interpret circuit diagrams, and develop suitable Arduino programs. As a result, students often lacked confidence and required considerable time to complete practical tasks.

Previous studies have highlighted the effectiveness of active learning, simulation-based learning, and project-based learning in improving students' understanding and engagement in technical education (Abramenka-Lachheb & Ozogul, 2022; Azid et al., 2023; Juera, 2022). However, many existing approaches focus on individual learning tools rather than providing a complete learning pathway that guides students from conceptual understanding to project implementation.

To address these challenges, FLASHDuino was developed as an integrated learning innovation that combines flashcards, digital simulation, AI-assisted programming, and physical project development. The innovation provides students with a structured learning experience that enables them to visualise circuits, test designs virtually, generate programming solutions, and implement projects successfully. Through this process, FLASHDuino aims to improve students' understanding of electronics concepts, enhance practical competencies, and create a more engaging learning experience.

1.1 Research Objectives

This study was conducted with the following objectives:

i. To develop FLASHDuino as a flashcard-based learning innovation that integrates Tinkercad simulation, AI-assisted Arduino programming, and physical project implementation.
ii. To evaluate the effectiveness of FLASHDuino in enhancing students' understanding of electronic circuit assembly and Arduino programming.
iii. To determine the levels of students' motivation and engagement towards learning electronics using FLASHDuino.

1.2 Research Questions

This study seeks to answer the following questions:

i. How can FLASHDuino be developed as an integrated flashcard-based learning tool for electronics education?
ii. To what extent does FLASHDuino improve students' understanding of electronic circuit assembly and Arduino programming?
iii. What are the levels of students' motivation and engagement towards learning electronics using FLASHDuino?

1.3 Significance of the Study

This study contributes to the advancement of teaching and learning practices in Technical and Vocational Education and Training (TVET) by introducing an innovative instructional approach that combines flashcard learning, digital simulation, artificial intelligence, and project-based learning.

For students, FLASHDuino provides a structured learning pathway that supports the gradual development of knowledge and practical skills. Students are guided from understanding circuit diagrams through flashcards to constructing circuits digitally, generating Arduino programming codes with AI assistance, conducting simulations, and finally implementing projects physically. This process helps students visualise abstract concepts and gain confidence in performing practical tasks.

For lecturers, FLASHDuino serves as a teaching aid that promotes active learning, student participation, and self-directed learning. The innovation reduces students' dependency on continuous lecturer assistance by encouraging exploration and problem-solving through guided learning activities.

For institutions, the implementation of FLASHDuino supports efforts to strengthen digital transformation initiatives and improve the quality of electronics education. The integration of emerging technologies such as artificial intelligence and simulation software aligns with national aspirations to enhance Industry 4.0 readiness among TVET graduates.

The findings of this study may also serve as a reference for educators and researchers interested in integrating flashcard-based learning, artificial intelligence, and project-based learning into technical education.

2.0 Literature Review

Active learning involves students actively participating in learning through discussion, problem-solving, and hands-on activities rather than passively receiving information. In TVET education, this approach is essential for developing both theoretical understanding and practical skills. According to Abramenka-Lachheb and Ozogul (2022), active learning enhances student engagement, critical thinking, and the application of knowledge in real-world

situations. FLASHDuino supports active learning through a structured process involving circuit interpretation, simulation, coding, testing, and project development.

Flashcards are effective learning tools that improve memory retention, concept understanding, and self-paced learning. Visual learning materials help students understand technical concepts more easily by reducing cognitive load and increasing clarity. In FLASHDuino, flashcards act as instructional guides that introduce circuit designs, project objectives, and component arrangements before simulation and implementation activities.

Digital simulation allows students to design, test, and evaluate circuits in a virtual environment before physical implementation. Juera (2022) highlighted that simulation-based learning improves access to practical training while reducing equipment-related risks and resource limitations. Tinkercad provides a user-friendly platform for circuit design, Arduino programming, and simulation. In FLASHDuino, Tinkercad helps students validate circuit functionality and strengthen their understanding before building physical prototypes.

Artificial Intelligence (AI) tools such as ChatGPT provide immediate learning support through explanations, examples, and programming assistance. Pedraja-Rejas et al. (2024) found that AI-enhanced learning can improve student engagement, problem-solving skills, and learning independence. In FLASHDuino, ChatGPT assists students in generating Arduino codes based on their circuit designs, helping them connect hardware concepts with programming skills.

Arduino is widely used in engineering and electronics education due to its affordability, flexibility, and ease of use. Arduino-based projects encourage students to apply theoretical knowledge through hands-on activities and real-world problem solving. Zadorozhnii (2024) reported that Arduino supports creativity, innovation, and technical skill development. In FLASHDuino, students use Arduino to transform validated designs and generated codes into functional prototypes.

Previous studies have shown the benefits of active learning, digital simulation, AI-assisted learning, and Arduino-based projects in technical education. However, these approaches are often implemented separately. Limited research has examined the integration of flashcards, Tinkercad simulation, AI-assisted programming, and Arduino implementation within a single learning framework, particularly in Malaysian TVET institutions. Therefore, this study introduces and evaluates FLASHDuino as an integrated learning

innovation designed to enhance student understanding, engagement, and practical competencies in electronics education.

3.0 Methodology

This study employed a quantitative research design to evaluate the effectiveness of FLASHDuino in enhancing students' understanding of electronic circuit assembly and Arduino programming. The study also examined students' motivation, engagement, and learning experiences when using FLASHDuino during electronics practical activities.

This study employed a quantitative descriptive research design to evaluate the effectiveness of FLASHDuino in supporting electronics learning among students. The study focused on students' perceptions of motivation, engagement, and learning effectiveness after participating in FLASHDuino learning activities. A structured questionnaire was used as the main instrument for data collection.

The study involved students enrolled in the Certificate in Electrical Technology programme at Sandakan Community College.
A total of 92 students participated in the study. Since all students who experienced the FLASHDuino learning activities were included, total population sampling was adopted.

3.1 FLASHDuino Learning Process

FLASHDuino was developed as a learning innovation that combines flashcards, digital simulation, artificial intelligence, and project-based learning. The learning process consisted of five stages:

Stage 1: FLASHDuino Flashcards
Students were given FLASHDuino flashcards containing project descriptions, circuit diagrams, component information, and expected project outcomes.

Stage 2: Circuit Development Using Tinkercad.
Students constructed the electronic circuits digitally using Tinkercad based on the information provided in the flashcards.

Stage 3: Arduino Programming Using ChatGPT
Students used ChatGPT to generate Arduino code according to the circuit design developed in Tinkercad.

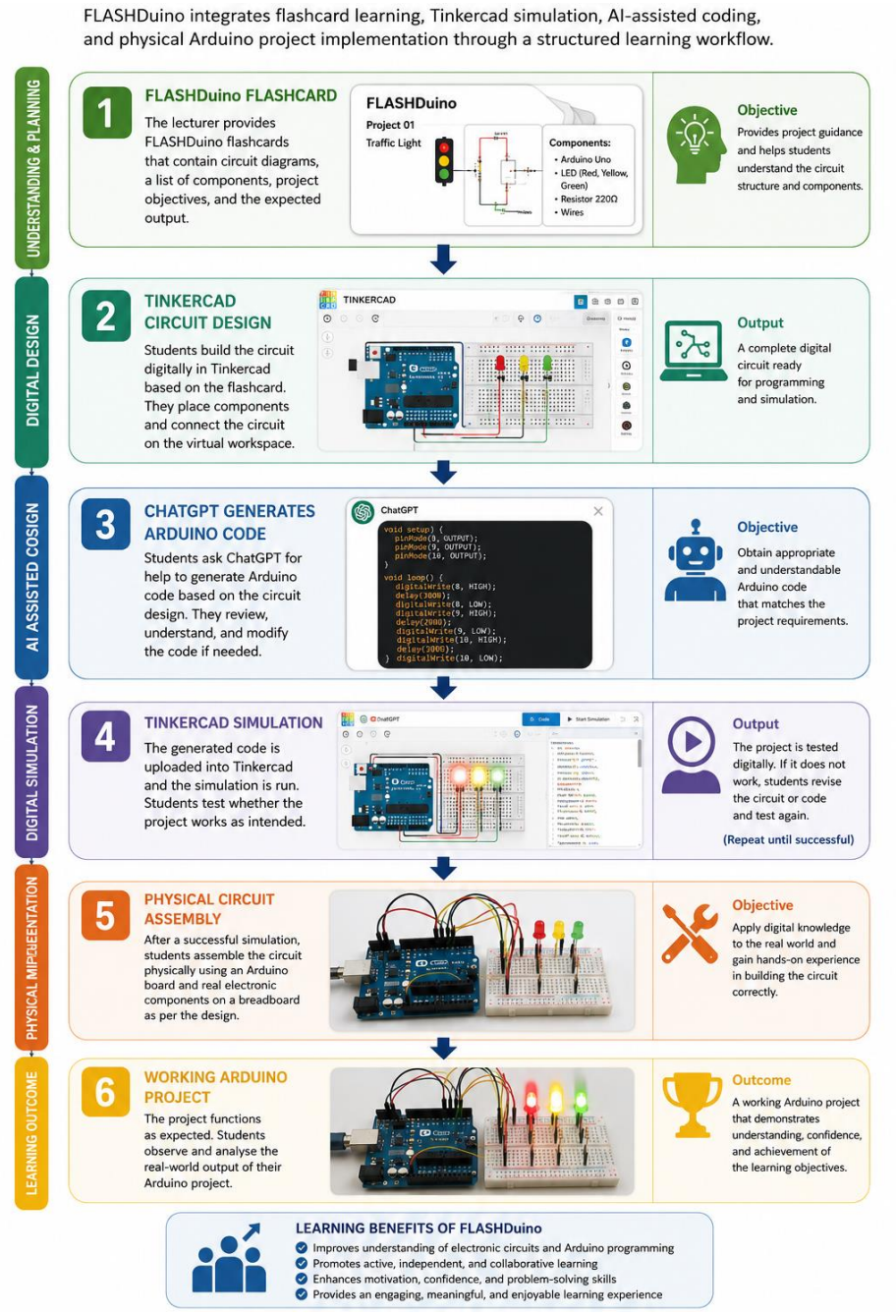
Stage 4: Simulation Testing
The generated code was tested through Tinkercad simulation to ensure that the project functioned as intended.

Stage 5: Physical Project Implementation

After successful simulation, students assembled the actual circuit using Arduino boards and electronic components.

The complete learning process is illustrated in Figure 1.

Figure 1: The FlashDuino Learning Process



3.2 Research Instrument

Data were collected using a structured questionnaire consisting of three sections:

Section A: Student Motivation
This section measured students' interest, confidence, and enthusiasm towards learning electronics using FLASHDuino.

Section B: Student Engagement
This section measured students' participation, collaboration, and involvement throughout the learning activities.

Section C: Learning Effectiveness
This section assessed students' perceptions of their understanding, problem-solving skills, and overall learning experience. Responses were measured using a five-point Likert scale, as shown in table 1**.**

Table 1: Likert Scale

Score	Evaluation Level
1	Strongly Disagree
2	Disagree
3	Neutral
4	Agree
5	Strongly Agree

The use of Likert scales is widely accepted in educational research for measuring attitudes and perceptions (Likert, 1932)

3.3 Data Collection Procedure

Students completed the FLASHDuino learning activities during practical sessions. Upon completion of all learning stages, the questionnaire was distributed to collect feedback regarding their learning experience.
Responses were collected and compiled for analysis.

3.4 Data Analysis

Data were analysed using the Microsoft Excel. The interpretation of mean scores was based on equal interval classification for a five-point Likert scale. This approach has been widely applied in educational research (Creswell & Creswell, 2018; Pallant, 2020).

Table 2: Interpretation of Mean Scores

Mean Score	Evaluation Level
1.00 – 1.80	Very Low
1.81 – 2.60	Low
2.61 – 3.40	Moderate
3.41 – 4.20	High
4.21 – 5.00	Very High

4.0 Results and Discussion

This section presents the findings obtained from the questionnaire. The results are discussed according to the three dimensions investigated in this study: motivation, engagement, and learning effectiveness.

4.1 Section A: Student Motivation Toward FLASHDuino

The results indicate that students were highly motivated when using FLASHDuino. The highest mean score was recorded for interest in learning electronics (M = 4.89), suggesting that the learning activities successfully attracted students' attention and interest as presented in table 3.

The combination of visual flashcards, digital simulation, AI-assisted programming, and practical project implementation created a more enjoyable and meaningful learning experience. Students were able to explore concepts independently while receiving immediate feedback through simulation and coding activities.

Table 3: Analysis of Survey Findings Section A

Item	Question	Mean	SD	Level
1	Interest in learning electronics	4.89	0.32	Very High
2	Improved understanding through flashcards	4.84	0.37	Very High
3	Enjoyment of Tinkercad simulation activities	4.79	0.41	Very High
4	Confidence in assembling circuits	4.83	0.38	Very High
5	Usefulness of ChatGPT for programming assistance	4.84	0.37	Very High
6	Encouragement towards independent learning	4.83	0.38	Very High
7	Increased motivation to attend class	4.81	0.40	Very High
8	Enthusiasm for project completion	4.82	0.39	Very High
	Overall Mean	4.83	0.38	

These findings support previous studies which reported that technology-enhanced learning environments can improve learner motivation and participation (Pedraja-Rejas et al., 2024).

4.2 Section B: Student Engagement in FLASHDuino Projects

Students demonstrated a high level of engagement throughout the learning activities. Many students actively participated in discussions, shared ideas with peers, and worked collaboratively to improve project outcomes. The opportunity to test circuits, generate Arduino code, and evaluate project performance encouraged students to become active participants in the learning process. As shown in table 4, these findings, suggest that FLASHDuino promotes active learning and supports student-centred instructional practices.

Table 4: Student Engagement

Item	Question	Mean	SD	Level
1	Active participation in discussions	4.88	0.33	Very High
2	Exploration of different circuit designs	4.78	0.42	Very High
3	Willingness to troubleshoot errors	4.83	0.38	Very High
4	Collaboration with peers	4.77	0.43	Very High
5	Active involvement during Arduino activities	4.80	0.41	Very High
6	Additional effort outside classroom hours	4.76	0.43	Very High
7	Contribution of ideas during projects	4.83	0.38	Very High
8	Satisfaction in sharing project outcomes	4.81	0.40	Very High
	Overall Mean	4.80	0.40	

4.3 Section C: Perceived Learning Effectiveness

The overall mean score indicates that students perceived FLASHDuino as an effective learning tool. The highest-rated item was improvement in problem-solving skills (M = 4.87). This suggests that students benefited from the step-by-step learning process that required them to analyse circuit designs, test solutions, and refine project outcomes as shown in table 5.

Table 5: Learning Effectiveness

Item	Question	Mean	SD	Level
1	Better understanding of electronic circuits	4.85	0.36	Very High
2	More interactive learning experience	4.84	0.37	Very High
3	Improved independent learning ability	4.84	0.37	Very High
4	Better connection between theory and practice	4.84	0.37	Very High
5	Continued use in future courses	4.86	0.35	Very High
6	Improved problem-solving skills	4.87	0.34	Very High
7	Better understanding of Arduino programming	4.82	0.39	Very High
8	Improved focus during learning activities	4.84	0.37	Very High
	Overall Mean	4.84	0.37	

The findings also indicate that FLASHDuino helped students connect theoretical concepts with practical implementation. Through simulation and project development, students gained a clearer understanding of how electronic circuits and Arduino programming work together. The findings show that FLASHDuino provides a structured and engaging learning experience for electronics students.

Unlike conventional approaches that often separate theory from practical work, FLASHDuino integrates flashcards, simulation, AI-assisted coding, and project implementation into a single learning process. This approach allows

students to progress gradually from understanding circuit diagrams to producing working Arduino projects.

The high levels of motivation, engagement, and learning effectiveness suggest that FLASHDuino can support both conceptual understanding and practical skill development. The integration of digital tools and hands-on activities also encourages active participation and independent learning.

Overall, FLASHDuino demonstrates strong potential as an innovative teaching and learning tool for electronics education within TVET institutions.

This study has several limitations. First, it was conducted at a single institution, Sandakan Community College, which may limit the generalisability of the findings to other TVET institutions. Second, the participants were limited to students from the Certificate of Electrical Technology Programme, and therefore the findings may not represent other technical disciplines. Third, the evaluation focused mainly on students' perceptions, engagement, and practical performance without employing a control group or standardised achievement measures. Finally, variations in students' use of ChatGPT, including differences in prompts and interaction strategies, may have influenced individual learning experiences.

Despite these limitations, the study provides useful insights into the integration of flashcards, digital simulation, artificial intelligence, and project-based learning in electronics education.

5.0 Conclusion

This study evaluated the effectiveness of FLASHDuino in supporting electronics learning among students. The findings revealed very high levels of motivation, engagement, and perceived learning effectiveness. Students responded positively to the use of flashcards, Tinkercad simulation, ChatGPT-assisted programming, and Arduino project implementation.

FLASHDuino provides a structured learning pathway that helps students understand electronic circuits and programming concepts while developing practical skills. The integration of digital technologies and hands-on activities creates a more meaningful and enjoyable learning experience.

Overall, FLASHDuino has strong potential to enhance teaching and learning practices in electronics education and support the development of future-ready TVET graduates.

Based on the findings of this study, several recommendations are proposed.

i. FLASHDuino should be expanded to include additional Arduino-based projects involving sensors, automation systems, and Internet of Things (IoT) applications.

ii. Future studies should involve a larger sample from multiple TVET institutions to improve the generalisability of findings.

iii. Experimental studies may be conducted to examine the impact of FLASHDuino on students' academic performance and technical competencies.

iv. Future versions of FLASHDuino could integrate QR codes, instructional videos, and online learning resources to further support self-directed learning.

v. Further research should explore the role of artificial intelligence tools such as ChatGPT in improving programming and problem-solving skills among TVET students.

The implementation of FLASHDuino offers several practical implications for electronics education and TVET practice.

For lecturers, FLASHDuino provides a structured instructional framework that simplifies the teaching of electronic circuit assembly and Arduino programming. The integration of flashcards, simulation, and AI-assisted learning enables lecturers to facilitate learning more efficiently while encouraging greater student independence.

For students, FLASHDuino creates a scaffolded learning pathway that reduces learning anxiety and improves confidence when dealing with technical tasks. Students can visualise concepts, test ideas, receive programming assistance, and validate project functionality before physical implementation.

For institutions, FLASHDuino represents a cost-effective innovation that supports digital transformation initiatives and strengthens the adoption of Industry 4.0-related technologies within TVET programmes.

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comments and suggestions during the development and validation of the research instrument and innovation.

Author Contributions

N. Hassan: Conceptualisation, innovation development, methodology, data collection, data analysis, manuscript preparation, and project administration.; **A.H.A. Karim**: Validation, review and editing, technical consultation, and manuscript refinement.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this manuscript. The study was conducted solely for educational and research purposes.

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