Design and Implementation of a Portable Smart Oscilloscope with Android Interface for Lab Applications

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Abstract
This study presents the design, development, and formative evaluation of a portable smart digital oscilloscope prototype, intended to address limited access to diagnostic tools in electronics laboratories within Technical and Vocational Education and Training (TVET) institutions. Built with a Raspberry Pi Pico microcontroller and the Scoppy Android application, the device enables real-time waveform visualization through mobile integration at low cost. A design-based development approach guided the construction, functional testing, and usability evaluation. Functional testing using standard waveform inputs demonstrated stable signal rendering, low latency, and adequate responsiveness for foundational electronics instruction. Usability was evaluated with 30 diploma students using a modified instrument adapted from the System Usability Scale (SUS) and Technology Acceptance Model (TAM), validated through expert review and pilot testing. The results confirm the feasibility and educational relevance of the prototype in supporting student-centered, mobile-assisted learning. Future work will expand testing across institutions and explore integration with structured teaching materials to maximize pedagogical impact.

Keywords: Electronics Education; Portable Oscilloscope; Raspberry Pi Pico; Scoppy; Usability Testing.

1.0 Introduction
Oscilloscopes are fundamental instruments in electronics education, enabling learners to visualize and analyze voltage signals in real time They reinforce concepts such as waveform behavior, timing, and fault diagnosis, and are central to hands-on learning in Technical and Vocational Education and Training (TVET) institutions. However, many polytechnics and other resource-limited institutions face persistent challenges: benchtop oscilloscopes are expensive, bulky, and limited in quantity, often leading to long student wait times and reduced engagement during laboratory sessions (Ingole et al., 2024). Similar issues are commonly observed in other developing countries, where limited lab infrastructure often constrains active, experiential learning (Ferreira et al., 2025).

Recent advances in microcontrollers, mobile applications, and wireless technologies have enabled the miniaturization of test equipment, including the development of portable smart oscilloscopes (Carminati & Scandurra, 2021). A notable example is Scoppy, an Android application that, when paired with affordable hardware such as the Raspberry Pi Pico, allows smartphones to function as oscilloscopes. Such systems provide a scalable and cost-effective alternative, aligning with mobile-assisted learning trends while offering opportunities to modernize electronics instruction.

In response to these challenges and opportunities, this study explores the design and implementation of a portable smart oscilloscope system intended for use in educational electronics labs. The system is built using the Raspberry Pi Pico microcontroller and is paired with the Scoppy application to display waveforms in real time through USB On-The-Go (OTG) communication. This approach not only addresses the limitations of existing equipment but also aligns with mobile-assisted learning trends by providing an accessible, low-cost solution for student use. The project includes the development of a functioning prototype, performance and usability evaluation, and the collection of preliminary user feedback to inform future improvements and classroom integration.

Current teaching and learning of electronic diagnostics in polytechnic laboratories are limited by (i) insufficient student-to-device ratios, (ii) the high cost and immobility of benchtop oscilloscopes, and (iii) the lack of features that support integration with mobile learning (Saenz et al., 2024; Wu et al., 2021). These gaps reduce opportunities for hands-on practice and diminish student confidence. There is thus a clear need for a portable, affordable, and pedagogically relevant oscilloscope system that maintains essential functionality while enhancing accessibility.

This study responds to the identified gap by focusing on the design, development, and preliminary usability testing of a portable smart digital oscilloscope system for educational use:

i. To design and construct a compact, low-cost prototype using the Raspberry Pi Pico.
ii. To integrate the system with the Scoppy Android application for real-time waveform visualization.
iii. To evaluate the prototype’s signal performance and usability in an educational laboratory setting.
iv. To collect user feedback to inform future improvements and classroom deployment.

2.0 Methodology

This study adopts a design-based development approach, emphasizing the iterative creation and evaluation of a portable smart digital oscilloscope prototype tailored for educational laboratory use. Design-based development was selected because it supports the integration of technical innovation with pedagogical needs in authentic educational contexts. Unlike linear experimental methods, this approach allows for iterative prototyping, testing, and refinement, making it particularly suitable for low-cost, technology-enhanced tools intended for classroom adoption (Haagen-Schützenhöfer & Hopf, 2020). The research process consists of three main phases: (1) system design and integration, (2) functional and usability testing in a lab setting, and (3) collection of user feedback to inform future improvements. The methodological focus is on technical feasibility and user acceptance, in line with a proof-of-concept scope suitable for early-stage innovation (Fowler & Leonard, 2021).

2.1 System Architecture and Block Diagram

The system architecture consists of three integrated layers:

i. Signal Acquisition Hardware: Built around the Raspberry Pi Pico microcontroller, which captures analog signals and communicates with a mobile device via USB OTG.
ii. Mobile Interface: Utilizes the Scoppy Android application for real-time waveform display and signal analysis.
iii. Connectivity & Enclosure: Standard BNC connectors, jumper wiring, and passive components integrated onto a custom PCB and housed in a 10 cm × 10 cm junction box.

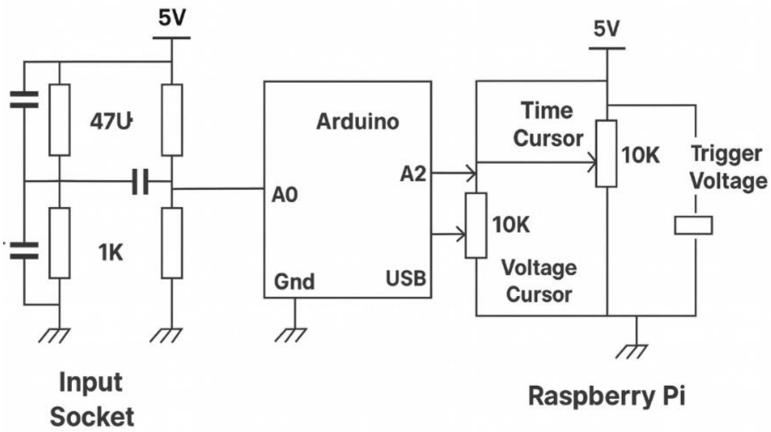

Figure 1: Block diagram of the smart digital oscilloscope system integrating Raspberry Pi Pico with Scoppy mobile interface and standard BNC-based signal input

2.2 Hardware Development

The hardware design aimed to balance cost-efficiency with functional reliability. Components used include:

i. Microcontroller: Raspberry Pi Pico (ARM Cortex-M0+ dual-core, 133

MHz) selected for its low cost, programmability, and support for Programmable I/O (Raspberry Pi Foundation, 2022).

ii. Connectivity: BNC to Alligator, BNC to Test Clip, and BNC to BNC cables for external signal input.

iii. Supporting Components: Resistors (1kΩ, 10kΩ), capacitors, push buttons, and jumper wires for signal routing and interface control.

iv. Assembly: Prototyped using general-purpose PCB before final mounting in a durable enclosure.

Total hardware cost was maintained under RM100, making the system replicable in low-resource academic settings.

2.3 Software Configuration: Scoppy Integration

The mobile oscilloscope interface was implemented using the Scoppy – Oscilloscope and Logic Analyzer application, which serves as the visual interface for signal acquisition and waveform display. As shown in Figure 2, the Scoppy is an open-source Android application designed to work with microcontrollers such as the Raspberry Pi Pico, making it highly suitable for educational and prototyping contexts. The integration process between the hardware and the mobile application involved the following key steps:

i. Firmware Installation: The Raspberry Pi Pico was flashed with Scoppy-compatible firmware using the Thonny IDE and the MicroPython UF2 loader. This firmware enables the Pico to function as a signal acquisition device for mobile analysis.

ii. Device Communication: The Pico was connected to an Android smartphone (running Android 10 or above) via a USB On-The-Go (OTG) cable. Upon connection, Scoppy version 0.7.3 detected the device automatically and initiated real-time data transmission.

iii. App Interface: The Scoppy application provided waveform visualization with adjustable time base, voltage scaling, and trigger controls. These features emulate key oscilloscope functionalities and allow waveform interpretation directly on the mobile screen.

Scoppy was selected due to its plug-and-play architecture, minimal setup requirements, and proven compatibility with the Raspberry Pi Pico. Its mobile-based interface supports flexible, BYOD-style learning environments, which are increasingly adopted in TVET institutions for enhancing accessibility and engagement in practical electronics education.

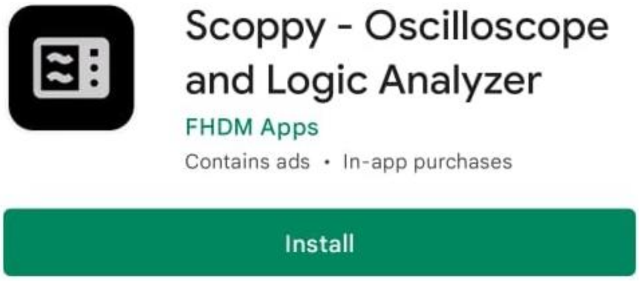

Figure 2: Scoppy application interface on Google Play Store

2.4 Prototype Testing and Evaluation

To determine the operational viability of the developed prototype, two phases of testing were conducted: functional testing and usability evaluation. These assessments were designed to examine whether the system met the minimum technical requirements and user expectations for classroom use, in line with the third objective of the study. The tests were conducted in a controlled electronics lab environment using standard waveform inputs and actual student users.

2.4.1 Functional Testing

The purpose of the functional testing phase was to evaluate the system's ability to capture, process, and display electronic signals reliably. This involved the following components:

i. Test Signals: The system was tested using square wave signals generated via Arduino PWM outputs and sinusoidal signals from a standard function generator.
ii. Observed Parameters: Key parameters such as signal responsiveness, waveform stability, latency, and display clarity were assessed using the Scoppy mobile interface.
iii. Verification: Output waveforms were benchmarked against expected signal characteristics based on known input parameters to confirm consistency and reliability.

The prototype was able to render waveforms clearly on the Android interface, with a latency of less than 50 ms and stable operation over a two-hour continuous test session. The system's sampling rate, limited to approximately 250 kHz by the firmware, was sufficient for low-to-mid frequency signals commonly encountered in diploma-level lab activities. These findings suggest that the system is functionally suitable for its intended educational context, even though it does not meet the specifications of industrial-grade oscilloscopes.

2.4.2 Usability Testing

The usability of the prototype was evaluated through a User Acceptance Test (UAT) involving 30 diploma students enrolled in an electronics course. The User Acceptance Test (UAT) instrument used in this study was adapted and modified from established instruments, primarily the System Usability Scale (SUS) by Brooke (1996) and constructs from the Technology Acceptance Model (TAM) by Davis et al. (1989), to suit the context of a mobile-based oscilloscope system for educational use. From the SUS, three core items were retained and reworded to suit the context of a mobile-based diagnostic tool, focusing on ease of use, interface clarity, and satisfaction. Two additional items from TAM were integrated to assess perceived usefulness and perceived suitability for lab-based learning. Each item was adjusted to reflect the specific educational and technological setting of the prototype.

To ensure contextual relevance, content validity was established through expert review involving two electronics lecturers and one instructional designer from the host institution. The adapted instrument was then pilot tested with five students who were not involved in the main study. Feedback from the pilot phase led to minor rephrasing of certain items for clarity and comprehension. The internal consistency of the adapted scale was evaluated using Cronbach's alpha, yielding a reliability coefficient of 0.82, indicating acceptable reliability for the context of exploratory usability testing.

A purposive sampling approach was applied to ensure participants had prior hands-on experience with conventional lab equipment, enabling meaningful comparison and feedback (Nyimbili & Nyimbili, 2024). The evaluation consisted of two components:

i. Quantitative Assessment: All 30 participants completed a structured questionnaire featuring five items rated on a 5-point Likert scale. The items assessed perceived ease of use, responsiveness, clarity of the user interface, suitability for lab work, and overall satisfaction.
ii. Qualitative Assessment: Based on their engagement level and responses, five students were invited to provide open-ended feedback. They were asked to elaborate on specific strengths, encountered limitations, and suggestions for further improvement.

This mixed-method approach provided both breadth and depth of insight: the questionnaire offered quantifiable trends across the cohort, while the open-ended responses added qualitative nuance to understand how the tool functioned in practice. The outcomes of both evaluations supported the initial design intent and revealed specific areas for refinement (Hou, 2021).

3.0 Results and Discussion

This section presents the findings of the prototype development and testing process, organized according to the four research objectives outlined earlier. The results are drawn from system construction, technical evaluation, integration with the Scoppy mobile interface, and feedback gathered through usability testing. Each subsection includes a discussion of the findings in relation to the system's intended educational function, highlighting strengths, limitations, and implications for future refinement and classroom implementation.

3.1 Design and Construction of a Low-Cost, Compact Oscilloscope Prototype

The development of the prototype was guided by the need to address equipment accessibility challenges commonly encountered in electronics laboratories, particularly within Technical and Vocational Education and Training (TVET) institutions. The system was constructed using a Raspberry

Pi Pico microcontroller, in combination with standard passive electronic components (resistors, capacitors), BNC connectors, and jumper wires. All components were assembled onto a general-purpose printed circuit board (PCB) and housed in a compact 10 cm × 10 cm enclosure, ensuring portability and ease of individual use.

The total cost of the prototype remained under RM100, a significant reduction compared to commercially available oscilloscopes. This outcome fulfills the first research objective by demonstrating that a functional, cost-effective, and portable oscilloscope prototype can be developed using readily available components. To contextualize the value and practicality of the prototype, a comparison was made against entry-level commercial oscilloscopes typically used in instructional laboratories. Table 1 presents a comparative analysis based on key technical and usability parameters.

As shown in Table 1, although the prototype has clear limitations in terms of sampling rate, bandwidth, and data storage, it offers distinct advantages in affordability, mobility, and usability. These characteristics make it especially suitable for foundational electronics education, where waveform analysis tasks are limited to low-to-mid frequency signals. Importantly, the affordability of the device (under RM100) suggests the feasibility of a one-student-one-device model, reducing waiting times that currently hinder practical learning in many TVET labs. This trade-off between technical precision and accessibility indicates that for introductory electronics education, scalability and usability may outweigh the need for high-end specifications. Such positioning reinforces the prototype's value as a pedagogical rather than industrial tool. These findings are consistent with Hupp et al., (2024), who highlighted that microcontroller-based diagnostic tools, despite technical constraints, provide significant pedagogical benefits when aligned with structured classroom use.

Table 1: Comparison of proposed prototype
and commercial entry-level oscilloscopes

Feature/Parameter	Proposed Prototype	Commercial Entry-Level Oscilloscope
Approximate Cost (RM)	~100	500–1500
Portability	High (handheld, 10 cm casing)	Low (benchtop unit)
Display	External (Android via Scoppy app)	Integrated LCD screen
Connectivity	USB OTG to smartphone	Probe input via BNC
Vertical Resolution	~8–10 bits (Pico ADC + firmware)	8–12 bits

Sampling Rate	~250 kHz (firmware-limited)	20–100 MS/s typical
Bandwidth	Up to ~100 kHz practical	20–50 MHz typical
Multi-Channel Support	Single/Dual (via Scoppy firmware)	2–4 channels standard
Data Storage / Export	Not available	USB or SD card export options
Learning Curve	Low (app-based interface)	Moderate to high
Power Source	USB-powered (5V)	AC mains
Ideal Use Case	Student prototyping, mobile lab environments	Industrial testing, advanced diagnostics

3.2 Integration with Scoppy for Real-Time Visualization

The integration of the hardware system with the Scoppy Android application via USB OTG was successfully achieved. Upon flashing the Raspberry Pi Pico with Scoppy compatible firmware, the app was able to recognize the device and display real-time waveform data without additional configuration. The app allowed users to control time base, voltage scaling, and triggering, meeting the requirements for typical educational use cases involving waveform identification, frequency estimation, and signal timing.

Prior research by Fahad (2022) and Karmakar et al. (2025) highlights the value of Scoppy as a mobile oscilloscope interface that reduces dependency on conventional PC setups. Our study reinforces this finding and confirms its suitability for classroom-adapted deployment. The successful integration demonstrates more than just technical feasibility; it points to a sustainable instructional model where low-cost hardware can leverage students' personal smartphones (BYOD). This reduces institutional costs and supports mobile-assisted learning, aligning with global shifts toward student-centered pedagogies. Compared with conventional benchtop scopes, this approach democratizes access by placing measurement tools directly in students' hands.

3.3 Evaluation of Functional Performance and Usability

This section presents the findings from both technical performance testing and usability evaluation of the prototype, in alignment with the third research objective. The purpose of these assessments was to determine whether the system fulfils basic operational standards for instructional use, particularly in resource-limited learning environments such as TVET institutions. Functional performance was evaluated through waveform acquisition trials using standard electronic signals, while usability was assessed through structured feedback from student users.

3.3.1 Functional Testing Results

The functional performance of the prototype was tested using square wave signals generated by Arduino boards and sine waves from signal generators. The tests were conducted in a controlled lab environment to simulate standard use-case scenarios in electronics instruction. The system's ability to detect, process, and display waveforms was observed and benchmarked against expected signal behaviours. Table 2 summarizes the key functional observations:

Table 2: Functional performance summary of the prototype

Parameter	Observation
Signal Detection	Clear waveform rendering on Scoppy
Sampling Limit (Firmware)	Functionally effective up to approximately 250 kHz
Latency	<50 ms (visually stable)
Input Voltage Range	~0–5 V (unbuffered input)
Operation Duration	Stable after 2-hour continuous testing

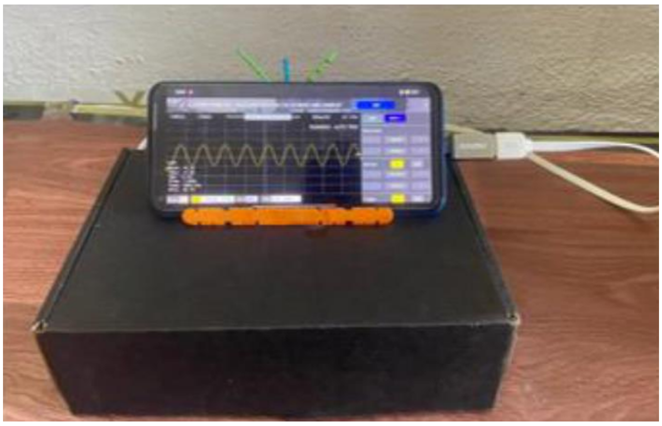

Figure 3: Prototype in operation, displaying sine waveform on Scoppy mobile interface

These findings indicate that the prototype meets the minimum technical requirements for basic laboratory activities involving waveform interpretation. Although the system does not match the precision or sampling capacity of industrial-grade oscilloscopes, its functionality aligns well with the pedagogical goals of foundational electronics training. The latency observed was low enough to allow real-time waveform tracking, and signal representation remained stable over an extended period. This suggests that even modest hardware configurations can provide sufficient accuracy for early electronics instruction. In practice, this enables institutions to prioritize accessibility and affordability without compromising core learning outcomes. Compared with Karmakar et al., (2025), who also demonstrated the sufficiency of low-frequency visualization, our findings strengthen the case that educational tools can be intentionally "good enough" to achieve teaching objectives while remaining financially viable.

3.3.2 Usability Evaluation Results

A structured User Acceptance Test (UAT) involving 30 diploma students was conducted to evaluate the usability of the prototype in a controlled lab environment. Participants completed a 5-point Likert-scale questionnaire assessing five key usability aspects: ease of setup and connection, interface clarity, responsiveness of waveform display, suitability for lab exercises, and overall satisfaction. In addition, five (5) students were purposively selected to provide qualitative feedback through open-ended questions.

As shown in Table 3, the quantitative results revealed consistently high ratings across all items. Specifically, students rated the system highly for ease of setup (M = 4.5, SD = 0.52) and overall satisfaction (M = 4.4, SD = 0.49), indicating a generally positive user experience. The moderate standard deviations suggest a reasonable level of agreement among participants.

Table 3: Mean scores and standard deviations for usability evaluation (n = 30)

Item	Mean Score (/5)	SD
Ease of setup and connection	4.5	0.52
Interface clarity (Scoppy UI)	4.2	0.64
Responsiveness of waveform display	4.1	0.71
Suitability for teaching lab exercises	4.3	0.58
Overall satisfaction	4.4	0.49

The qualitative feedback further supports the quantitative findings. Students reported that the device was easy to set up and more engaging compared to traditional benchtop oscilloscopes. Several users commented on the clarity and responsiveness of the mobile interface, particularly for basic waveform interpretation tasks. However, some noted challenges with the limited zoom and vertical scaling functions in the Scoppy app, as well as the absence of waveform export or data logging features. Suggestions for improvement included the integration of multi-channel input, enhanced signal stability at higher frequencies, and additional analysis tools within the app.

These insights underscore that usability is as critical as technical adequacy for classroom adoption. High ease-of-use ratings imply that students are less intimidated and more willing to experiment, supporting active and student-centered learning. At the same time, the feedback about missing features provides a roadmap for iterative refinement, balancing simplicity with advanced functionality. This aligns with Ingole et al. (2024), who emphasized that intuitive, low-barrier mobile tools can significantly increase engagement while gradually introducing students to more complex measurement tasks.

4.0 Conclusion

This study introduced and evaluated a low-cost, portable digital oscilloscope prototype designed for instructional use in electronics education, particularly within resource-constrained TVET environments. Developed using the Raspberry Pi Pico microcontroller and integrated with the Scoppy Android application, the system demonstrates the feasibility of affordable, mobile-assisted diagnostic tools for classroom practice. The novelty of this work lies in its portability, affordability, and integration with smartphones, enabling a potential one-student-one-device model. This shifts oscilloscopes from being shared institutional resources to personal learning tools, supporting more student-centered and flexible engagement in electronics laboratories.

Looking ahead, further research should explore broader usability testing across diverse institutions and include lecturer perspectives to assess scalability and integration into teaching frameworks. Longitudinal studies are also needed to examine the prototype’s effectiveness in improving student learning outcomes and confidence in diagnostics over time. In addition, the development of structured instructional resources such as guides, classroom modules, and user support materials would facilitate smoother adoption and enhance pedagogical impact.

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Author Contributions

M.A.I. Sazali: Conceptualisation, Data Collection, Data Curation, Validation,Writing; **M.H. Ahmad:** Validation, Writing-Reviewing, Supervision; **S.N. Razali:** Reviewing and Editing; **H. Ilyasu:** Reviewing.

Conflicts of Interest

The manuscript has not been published elsewhere and is not under consideration by other journals. All authors have approved the review, agree with its Submission and declare no conflict of interest in the manuscript.

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