Advanced Portable ABS Sensor Simulator (APSSS) as an Innovative Teaching Aid for ABS Topic

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Abstract. This study presents the development and evaluation of the Advanced Portable ABS Sensor Simulator (APSSS) as an innovative teaching aid for the Antilock Braking System (ABS) topic in the SAU10053 Brake System course offered at Malaysian TVET institutions. The simulator was designed to address the challenges of conventional teaching methods that rely on real vehicles, which are costly, require large workshop space, and pose safety risks. APSSS integrates real ABS components with electronic systems and mobile connectivity, enabling students to observe sensor signals and system operations in a safe, interactive, and practical way. The research involved prototype development, functional testing, and a quasi-experimental study with 27 students. Results indicated significant improvements in students' understanding, engagement, and confidence, while also reducing instructional time, cost, and safety risks. The findings highlight APSSS as a sustainable and scalable solution to enhance teaching and learning in automotive education. This innovation not only bridges the gap between theory and practice but also supports the Ministry of Education's vision to strengthen digital-based teaching in line with Industry 4.0.

Keywords: Antilock Braking System, teaching innovation, simulator, TVET, automotive education, APSSS.

1. Introduction

Antilock Braking System (ABS) is a key safety technology in modern automotive systems, evolving rapidly with the integration of electronic control (Kumar et al., 2021). The main function of ABS is to prevent wheel lock-up during sudden braking, helping drivers maintain steering control and reducing braking distance under certain conditions (Lee et al., 2022). In technical and vocational education and training (TVET), deep understanding of ABS is crucial as it relates directly to road user safety and technical skill mastery (Rahman et al., 2021). However, traditional teaching methods often rely heavily on theoretical explanations, video demonstrations, or using real vehicles, which involve high costs, require large spaces, and carry safety risks (Idris et al., 2020). Recent studies emphasize that integrated digital simulation tools can significantly improve student understanding and engagement (Zulkifli et al., 2020). Therefore, APSSS was developed as a compact simulator that demonstrates real ABS function while reducing costs, time, and risk, aligning with the Ministry of Education Malaysia's goals to strengthen digital-based PdP and support Industry 4.0 (MOE, 2022).

1.1 Research Background

SAU 10053 Braking System is a course included in the Light Vehicle Servicing Certificate curriculum structure at a community college. The Braking System course is designed to train students' skills on the braking system by practicing real-world practical work. Students are trained to service the master cylinder, servo, disc brakes, drum brakes, parking brakes, and Antilock Braking System (ABS). For Topic 5, the Antilock Braking System (ABS), lecturers are required to explain to students how the Antilock Braking System controls pressure when stopping a vehicle. This explanation can only be done with the help of a video because the process involves signal processing between mechanical and electronic components. The signal transmission process that occurs in the ABS braking system is difficult to explain without examples of the components involved and a related demonstration. Therefore, this innovation project was developed to design a tool that can make the PdP (Teaching and Learning) process more interesting and interactive in a "real" way to give students a better understanding and make it easier for lecturers to teach the chapter related to ABS.

In addition, a brief study was conducted to determine the effectiveness of this APSSS in helping students understand the ABS topic, and so that the data obtained can be used to improve the APSSS system tool and provide a better understanding to students

1.2 Problem Statement

Teaching the Antilock Braking System (ABS) topic in technical and vocational education (TVET) institutions often faces significant challenges. Conventional instructional methods are primarily theoretical, relying heavily on videos and explanations without hands-on exposure. These approaches fail to adequately convey the complexity of ABS components and their real-world functionality, limiting student's understanding and practical competence. Furthermore, demonstrations using actual vehicles are costly, require large physical space, and pose safety risks to students during practical sessions. Due to budget and infrastructure limitations, many institutions are unable to offer effective practical training on ABS systems, resulting in a gap between theoretical knowledge and real-world application. To address these issues, the Advanced Portable ABS Sensor Simulator (APSSS) was developed as a compact, cost-effective, and safe alternative to traditional vehicle-based teaching. It enables realistic demonstrations of ABS sensor functionality in a classroom setting, encouraging more interactive and engaging learning experiences.

However, despite its promising design, the actual effectiveness of APSSS as a teaching aid has not been fully evaluated. There is a lack of empirical evidence on how APSSS impacts student learning outcomes, engagement, and readiness for industry. Therefore, this study also aims to assess the effectiveness of APSSS in improving students' understanding, enhancing teaching efficiency, and supporting the development of competent, industry-ready graduates in the automotive field.

1.3 Objective

i) To develop the Advanced Portable ABS Sensor Simulator (APSSS) as a compact and cost-effective teaching aid for the Antilock Braking System (ABS) topic.
ii) To evaluate the effectiveness of APSSS in enhancing students' understanding of ABS concepts and functions.
iii) To assess the impact of APSSS on the interactivity, safety, cost, and time efficiency of teaching and learning sessions.

1.4 Research Question

i) How can the Advanced Portable ABS Sensor Simulator (APSSS) be developed as a compact and cost-effective teaching aid for the Antilock Braking System (ABS) topic?
ii) How effective is APSSS in enhancing students' understanding of ABS concepts and functions?
iii) What is the impact of APSSS on the interactivity, safety, cost, and time efficiency of the teaching and learning process?

1.5 Scope

This study focuses on the development and evaluation of the Advanced Portable ABS Sensor Simulator (APSSS) as a teaching aid for the Antilock Braking System (ABS) topic within the SAU10053 Brake System course. The scope includes:

i) The design and prototyping of the APSSS device using mechanical and electronic components relevant to real ABS systems.

ii) The implementation of APSSS in teaching and learning sessions at Kolej Komuniti Rompin involving students enrolled in the Light Vehicle Servicing Certificate program.
iii) The assessment of students' understanding before and after the use of APSSS.
iv) The collection of feedback from students and instructors regarding usability, effectiveness, safety, and teaching efficiency.
v) This study does not include long-term industrial testing or comparison with other commercial simulators.

1.6 Study Significance

This study is significant for several reasons:

i) Improved Teaching and Learning: By integrating APSSS into the classroom, the study promotes a more interactive and hands-on learning experience, bridging the gap between theory and practical application.
ii) Cost and Space Efficiency: The APSSS provides a low-cost alternative to full-sized vehicle demonstrations, making it especially useful for institutions with limited resources or space.
iii) Enhanced Student Competence: The use of APSSS enables students to observe and interact with real-time ABS sensor signals, improving their technical understanding and diagnostic skills relevant to the automotive industry.
iv) Safety and Accessibility: The simulator minimizes physical risks associated with real vehicle handling, offering a safer learning environment for students.
v) Support for TVET Goals: The study supports the objectives of the Ministry of Education in promoting digital-based and simulation-driven teaching approaches aligned with Industrial Revolution 4.0 initiatives in TVET institutions.

2. LITERATURE REVIEW

Antilock Braking System (ABS) is widely recognized as a crucial safety feature that prevents wheel lock-up during emergency braking, allowing drivers to maintain steering control (Lee et al., 2022). Its integration into modern vehicles has evolved alongside advances in electronic control systems (Kumar et al., 2021). In technical and vocational education and training (TVET), mastery of ABS concepts is essential because it equips students with practical skills relevant to industry demands (Rahman et al., 2021). However, studies by Idris et al. (2020) reveal that traditional teaching methods—using real vehicles or static demonstrations—often involve high costs, large space requirements, and safety risks.

Research supports using simulation-based teaching aids to overcome these barriers. Rahman et al. (2021) found that simulators improved students' conceptual understanding, while Zulkifli et al. (2020) emphasized that interactive digital tools significantly increased student motivation and engagement. Despite these benefits, existing simulators for ABS training are often bulky, expensive, or limited to theoretical software without real hardware integration (Idris et al., 2020; Kumar et al., 2021). This reduces their practicality and affordability for daily teaching use in TVET institutions, where budgets and workshop space are often constrained.

Furthermore, aligning teaching tools with Industry 4.0 trends has become increasingly important. Modern TVET strategies emphasize integrating digital technologies, hands-on learning, and real-time data visualization to better prepare students for future industry requirements (MOE, 2022). In this context, APSSS uniquely combines physical ABS components with mobile device connectivity, providing an interactive and realistic learning experience that addresses cost, portability, and relevance to digital learning objectives. This review establishes the context and need for APSSS as an innovative tool to enhance teaching and learning (PdP) effectiveness in the ABS topic.

Recent studies have placed increasing emphasis on evaluating the effectiveness of simulation-based teaching tools in enhancing learning outcomes. Ahmad et al. (2019) reported that hands-on simulators not only improved knowledge retention but also boosted learners' confidence in applying technical concepts during practical sessions. Their findings were echoed by Zulkifli et al. (2020), who observed that learners exposed to interactive simulation environments demonstrated significantly better diagnostic skills and were more engaged throughout the learning process.

The effectiveness of simulators is often measured through improvements in student comprehension, practical skill acquisition, and the ability to apply theoretical knowledge in real-world scenarios (Rahman et al., 2021). In the context of ABS, where system behavior involves real-time sensor input and mechanical response, visualizing signal outputs through simulators like APSSS enables students to bridge the gap between theory and practice more effectively. Moreover, APSSS offers measurable benefits in teaching efficiency. Its portability and ease of setup significantly reduce preparation time for instructors, while eliminating the risks associated with real vehicle handling (e.g., lifting vehicles, dismantling wheels) during demonstrations. According to Hassan et al. (2020), such innovations promote safer, faster, and more controlled teaching environments, especially in constrained workshop conditions.

Preliminary evaluations of APSSS have shown that it enhances students' motivation, supports deeper understanding of sensor behaviors, and encourages independent exploration of system functionality. These outcomes are consistent with the broader pedagogical shift in TVET towards student-centered and technology-enhanced learning, which emphasizes not just content delivery but also learner engagement, safety, and industry relevance (Ministry of Education Malaysia [MOE], 2022).

3. Research Methodology

3.1 Project Development

This study involved several detailed phases:

i) **Design phase:** Developing APSSS based on PdP needs analysis and reviewing existing simulation tools, considering cost, size, safety, and usability.
ii) **Prototype development phase:** Building mechanical components (hub & ABS rotor, wheel shaft) and integrating electronics (DC motor, ABS sensor, speed controller).
iii) **Function testing phase:** Verifying that ABS sensor output can be displayed on smartphones via the SmartScope app.
iv) **Effectiveness evaluation:** Collecting qualitative feedback from lecturers and students on effectiveness, safety, time and cost savings, and interactivity.

For phases 1 to 3, the study involves project development, where the combination of these phases can be translated into the flowchart in Figure 1. The flowchart in Figure 1 shows the full process of producing the APSSS innovation. After the product concept and design are finalized, the subsequent process is divided into mechanical and electronic components before being integrated. Figure 2 and Figure 3 detailing how the process for completing these components is carried out.

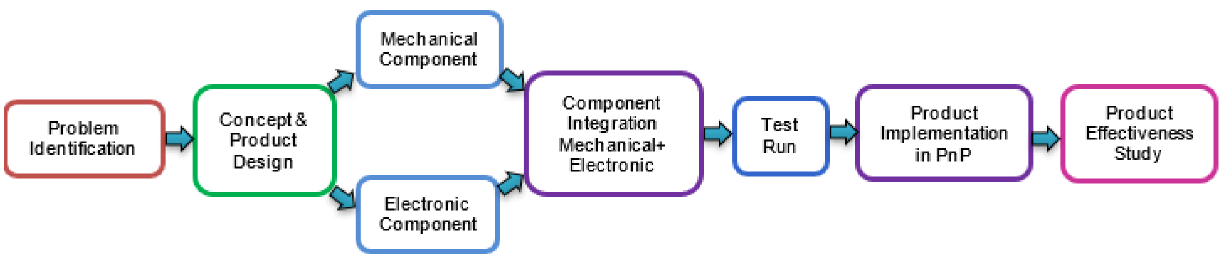


Figure 1. Flowchart of Project Process

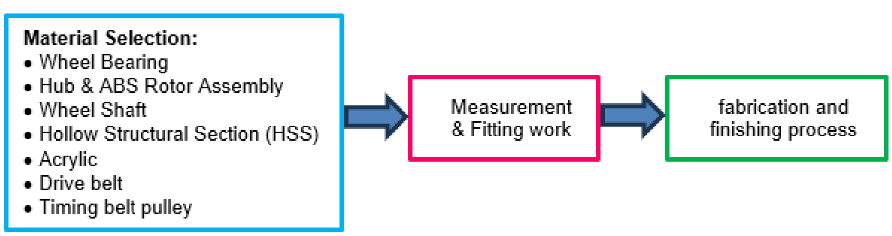


Figure 2. Mechanical Component Manufacturing Process

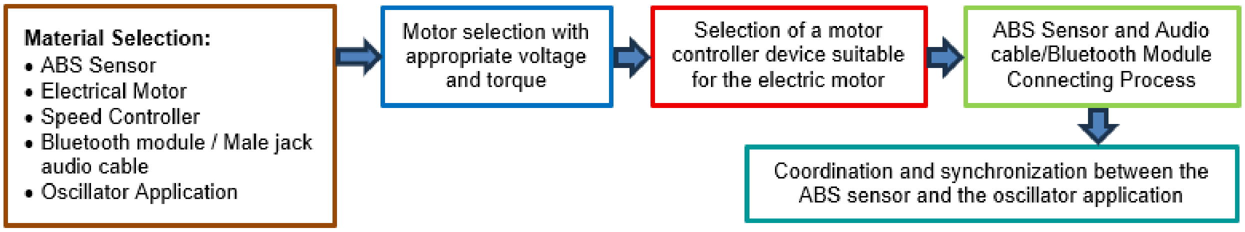


Figure 3. Electronic Component Assembling Process

3.2 Project Components

The APSSS is a device that integrates two core elements: a mechanical component and an electronic component. The mechanical component, as illustrated in Table 1, comprises a combination of several parts. A detailed list of these mechanical components can be found in Table 1 below

Table 1. Mechanical Components of APSSS

Bil.	Nama Komponen	Model / Spesifikasi
1	Wheel Bearing	Proton Waja
2	Hub & ABS Rotor Assembly	Proton Waja (rear)
3	Wheel Shaft	Proton Saga (used)
4	Hollow Structural Section (HSS)	1” x 2”
5	Acrylic	1’ x 1’
6	Drive belt	3D printer timing belt
7	Timing belt pulley	20 teeth 5mm

Without the help of electronic components, the mechanical components cannot function on their own to process signals. Most modern vehicles now rely on electronics rather than being purely mechanical, unlike older generations of vehicles. This integration of mechanics and electronics provides significant benefits to users, keeping pace with current times. Therefore, the integration of both mechanical and electronic components in APSSS makes it an innovative, engaging, and interactive device. The electronic components used are listed in Table 2 below.

Table 2. Electronic Components of APSSS

Bil.	Nama Komponen	Model / Spesifikasi
1.	ABS Sensor	Proton Waja (rear)
2.	Motor Elektrik	12v DC
3.	Speed Controller	3v – 20v
4.	Bluetooth module / Male jack audio cable	3.5mm
5.	Oscillator Application	SmartScope Oscillospcope Apps

3.3 Design Concept Evaluation/Criteria

The Portable ABS Sensor Simulator was conceptualized based on experiences and observations of problems encountered during the Teaching and Learning (PdP) process, where lecturers had to provide theoretical explanations without being able to demonstrate physically to students. Therefore, the design features that need to be produced to ensure this innovation is suitable for PdP use are as follows:

a) Designing the base and pillars to allow the wheel shaft to be positioned and the hub assembly to be mounted on it.
b) Designing the base to place the electric motor and adjusting the length of the drive belt to suit the desired height.

Figure 4. Process of making the electric motor base

c) Selecting an electric motor with appropriate speed and torque to rotate the hub assembly so that the ABS rotor/gear can rotate together.
d) Selecting a drive belt that matches the wheel hub size.
e) Selecting the appropriate type and size of hollow structural section (HSS) for producing the base and pillars.

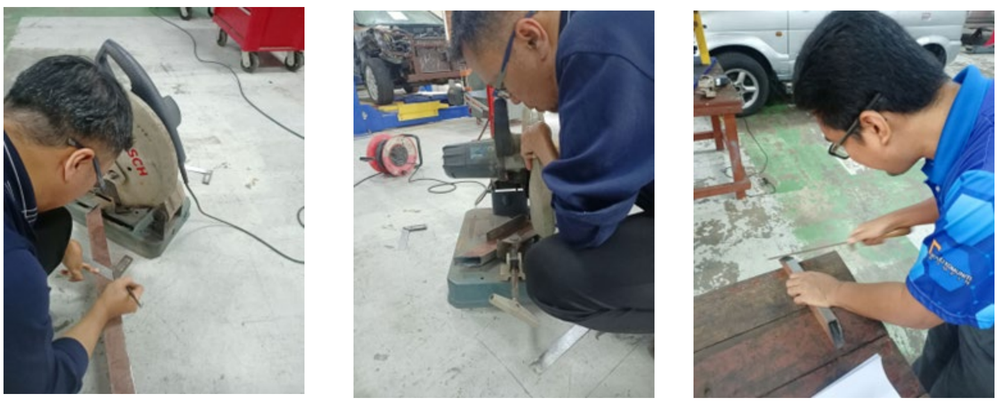


Figure 5. Measurement, cutting, and finishing process

f) Finishing process and selection of acrylic as the base cover.

Figure 6. Process of making the base cover

g) Selecting a suitable application for generating output from ABS sensor readings to be displayed on a mobile phone.
h) The innovative product produced must meet PdP requirements and have commercial potential.
i) Adding Bluetooth functionality for digital connection.

Figure 7. Product Test Run

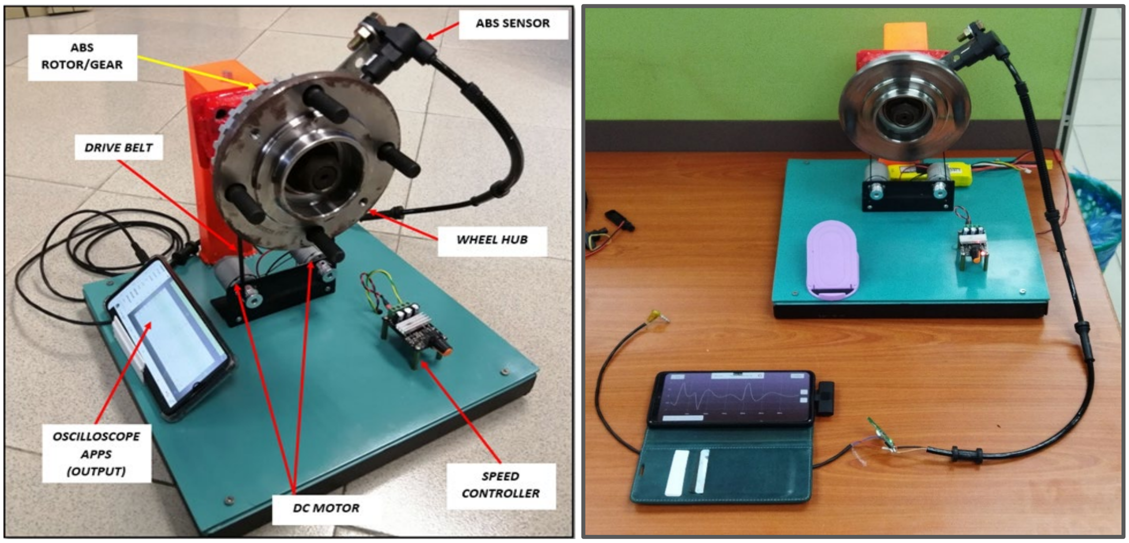


Figure 8. Final Product Advanced Portable ABS Sensor Simulator (APSSS)

Figure 9. The ABS output waveform is functioning normally

Figure 10. The ABS output waveform when there are abnormal things happen

3.4 Effectiveness Assessment Method

3.4.1 Study Sample

The respondents for this study consist of 27 students from the Automotive or Light Vehicle Servicing (SKR) program in Semester 1 of the 2024/2025 academic session (Session 1 and Session 2) at Kolej Komuniti Rompin. The sample size was determined based on the sample size determination table by Krejcie and Morgan (1970).

3.4.2 Research Instrument

The data collection process for this study employed a Google Form-based questionnaire as the primary research instrument, which was distributed to selected respondents. The questionnaire was adapted from a previous study titled "The Effectiveness of a Spark Plug Tester in Enhancing Students' Understanding and Skills in Engine Electrical Systems among SKR Students at Kolej Komuniti Rompin" by Mohd Roslan & Mohd Rasidi (2018).

Based on previous findings, the researchers believe that respondents will provide positive feedback to the questions presented. A five-point Likert scale was used, tailored to suit the research questions. Respondents were required to indicate their answers directly through the Google Form application. According to Mohd Majid (1994), the Likert scale used in this study has a high reliability level, reaching up to 85 percent. The interpretation and values of the Likert scale are shown in Table 3.

Table 3. Interpretation and values of the Likert scale

Likert Value	Interpretation
1	Strongly Disagree
2	Disagree
3	Not Sure
4	Agree
5	Strongly Agree

Microsoft Excel 2019 was used to analyze all the collected data. Descriptive analysis was conducted using mean score interpretation as suggested by J.W. Creswell (2005) in his well-known research methodology book, Educational Research: Planning, Conducting, and Evaluating Quantitative and Qualitative Research. The interpretation of mean scores adopted from Creswell (2005) is as Table 4:

Table 4. Mean Interpretation

Min Score Range	Mean Interpretation
1.00 - 1.80	Strongly Disagree
1.81 - 2.60	Disagree
2.61 - 3.40	Not Sure
3.41 - 4.20	Agree
4.21 - 5.00	Strongly Agree

3.4.3 ADDIE Model

This study adopts the ADDIE instructional design model as the underlying framework for the development and evaluation of the Advanced Portable ABS Sensor Simulator (APSSS). The ADDIE model, consisting of Analysis, Design, Development, Implementation, and Evaluation, provides a systematic approach to ensure that the innovation aligns with pedagogical goals and student learning needs. During the Analysis phase, the instructional challenges in teaching ABS were identified, such as safety, cost, and space limitations. In the Design phase, the simulator was conceptualized to overcome these barriers by integrating real ABS components with digital connectivity. The Development phase involved prototyping mechanical and electronic systems, while the implementation phase tested the tool with students in real classroom settings. Finally, in the evaluation phase, data were collected on its impact on student understanding, safety, engagement, and instructional efficiency. The adoption of ADDIE ensures that the APSSS is not only technically functional but also educationally effective.

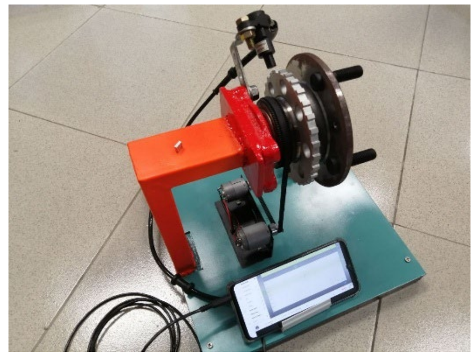
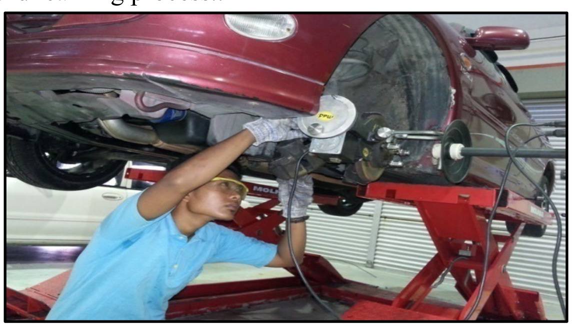
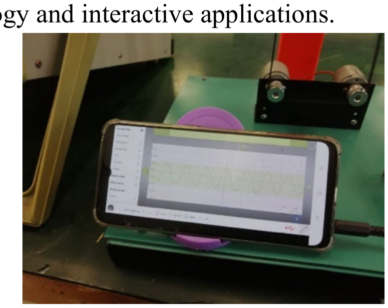
4. RESULTS & FINDING

4.1 Impact

At the Automotive Workshop of Kolej Komuniti Rompin, vehicles are used in the teaching and learning process for the SAU10053 Brake System course. Although using a complete brake system on a vehicle can help students master brake system components and operations, several issues have been identified that could be addressed in the Table 5:

Table 5. Impact before and after using APSSS

Bil	Before	After
1	**Buy & Maintenance Cost**	
	A complete ABS braking system installed on a vehicle involves high procurement costs and requires regular maintenance. 	The innovation developed through this project helps reduce maintenance and material costs, as students can learn the concepts of the ABS system directly through the simulator
2	**Injury Risk (Safety Aspect)**	

	Students are required to remove the vehicle's wheels and elevate the vehicle to observe components of the ABS system, particularly the sensor and ABS rotor located at the bottom of the vehicle. This exposes them to potential minor accidents, as the process involves the use of tools and equipment such as safety stands or lifters. This poses a significant risk, especially for new or inexperienced students. 	The use of APSSS reduces the risk and likelihood of injury, as it is a compact and user-friendly tool that can be safely handled by students. 
3	**Space Saving**	
	Using a full brake system on an actual vehicle takes up a large amount of workshop space during the teaching and learning process.. 	In contrast, APSSS helps reduce workshop space usage and can be produced in larger quantities to accommodate a high number of students without requiring excessive space.
4	**Time Efficiency**	
	The process of removing vehicle tyres and lifting the vehicle is time-consuming, as both students and lecturers need to prepare the necessary equipment.	With the simulator, students can directly identify the components involved in the ABS system as they are already readily accessible
5	**Interactive Learning**	
	The operational concept of the ABS braking system cannot be effectively explained without the aid of videos, and students need to observe the actual components involved. Moreover, students are often unable to fully grasp the workflow of the ABS system when it is only explained theoretically, which can be less engaging and somewhat monotonous.	With the use of APSSS, the output signals can be directly displayed on mobile devices, capturing students' interest through the integration of modern technology and interactive applications. 

6	**Innovation Product Exhibition**	
	Innovation product exhibitions often rely on buntings and printed materials, which tend to attract limited public interest to the exhibition booths. 	The APSSS makes it easier for lecturers and users to transport and showcase the product at any exhibition due to its compact and lightweight design. It also draws greater attention from visitors, especially school students and individuals from the automotive field, who are eager to witness ABS technology in action.

4.2 Research Question

4.2.1 Question 1

To identify whether lecturers possess the skills to use teaching aids (APSSS) in the teaching and learning process, a descriptive analysis was conducted to determine the mean values. The results of the analysis are presented in the Table 6:

Table 6. Mean Scores of Lecturer's Skills in Using Teaching Aids (APSSS) in Teaching and Learning (T&L)

No.	Item	Mean Score	Mean Interpretation
A1.	The demonstration delivered by my lecturer on how to use the Advanced Portable ABS Sensor Simulator convinced me	4.33	Strongly Agree
A2.	My lecturer was able to demonstrate the use of the Advanced Portable ABS Sensor Simulator during practical sessions efficiently and effectively	4.37	Strongly Agree
A3.	The steps taken by my lecturer in using the Advanced Portable ABS Sensor Simulator were well-organized and easy to understand	4.33	Strongly Agree
A4.	My lecturer used the Advanced Portable ABS Sensor Simulator appropriately	4.38	Strongly Agree
A5.	My lecturer is skilled in using the Advanced Portable ABS Sensor Simulator to assist students who face difficulties during practical sessions	4.33	Strongly Agree
A6.	I have confidence in my lecturer's demonstration of the Advanced Portable ABS Sensor Simulator	4.22	Strongly Agree
	Overall Mean Score: N = 27	**4.33**	**Strongly Agree**

Based on Table 6, the overall mean score for the lecturers' skills aspect is 4.33, which falls under the "Strongly Agree" interpretation level, as referenced in Table 4. The highest mean score was recorded for Item A4 (mean = 4.38). Items A2 at the second highest with mean score 4.37, meanwhile items A1, A3 and A5 recorded the same mean score, which was the third highest, at 4.33. The lowest mean score was recorded for Item A6, with a value of 4.22, which still within the "Strongly Agree" interpretation level.

4.2.2 Question 2

Same descriptive analysis was used to determine the mean scores in identifying the perceptions of SKR students at Kolej Komuniti Rompin before and after the use of the APSSS in teaching and learning. The results of the analysis are presented in the Table 7:

Table 7. Mean Scores of SKR Students' Perceptions at Kolej Komuniti Rompin Before and After the Use of APSSS in Teaching and Learning

Bil	Item	Before Use Mean Score	Mean Interpretation	After Use Mean Score	Mean Interpretation
B1.	Increases students' interest in learning	2.93	Not Sure	4.07	Agree
B2.	Makes the teaching and learning process for the vehicle charging system more engaging	2.93	Not Sure	4.07	Agree
B3.	Shortens the time needed by lecturers to demonstrate the vehicle charging system during practical sessions	2.93	Not Sure	4.14	Agree
B4.	Improves students' understanding of the vehicle charging system theory compared to methods without using the APSSS	2.93	Not Sure	4.19	Agree
B5.	Helps students better understand the real-life application of the vehicle charging system theory	2.93	Not Sure	4.26	Strongly Agree
B6.	Enhances students' skills in vehicle charging systems	2.93	Not Sure	4.19	Agree
B7.	Reduces workshop accidents caused by students not understanding basic vehicle charging system maintenance techniques	2.93	Not Sure	4.07	Agree
B8.	Builds students' confidence in carrying out practical work on vehicle charging systems	2.93	Not Sure	4.19	Agree
B9.	Reduces damage to tools and components of the vehicle charging system	2.93	Not Sure	4.15	Agree
Overall Mean Score: N = 27		**2.93**	**Not Sure**	**4.15**	**Agree**

Referring to Table 7, the mean score for students' perceptions before the use of APSSS in teaching and learning (T&L) shows an overall average categorized as not sure/uncertain, with a mean value of 2.93. All points received uncertain feedback, with respective mean scores of 2.93 based on the interpretation in Table 3.

In contrast, the interpretation of mean scores for all nine items after the use of APSSS in T&L fell into the agree category, with an overall average mean value of 4.15. Item B5 achieved the highest mean score of 4.26, while the lowest, though still in the strongly agree category, was recorded by item B1 and B2 with a mean score of 4.07. These responses indicate that the respondents agree that the use of APSSS in T&L has had a positive impact, while also providing added value to their learning experience.

4.2.3 Question 3

The impact of using the APSSS in Teaching and Learning for students, obtained through descriptive analysis, is shown in the Table 8:

Table 8. Mean Score of the Impact of APSSS Usage in Teaching and Learning for Students

Bil	Item	Mean Score	Mean Interpretation
C1.	The use of APSSS can make the teaching and learning (T&L) process more engaging and less monotonous	4.22	Strongly Agree
C2.	It enables students to be more alert when performing practical tasks related to the vehicle charging system.	4.26	Strongly Agree
C3.	It enhances students' proficiency in conducting practical work on the vehicle charging system.	4.22	Strongly Agree
C4.	It shortens and simplifies the duration of practical demonstrations for the vehicle charging system	4.07	Agree

C5.	It provides preliminary knowledge about the practical process of the vehicle charging system before it is carried out.	4.07	Agree
C6.	It can improve students' achievement in the subject of vehicle charging systems	4.11	Strongly Agree
Overall Mean Score: N = 27		**4.16**	**Agree**

The interpretation of the mean score for the impact of using the APSSS is "Agree", as obtained from the analysis conducted for all research questions. The overall mean score recorded is 4.16. Item C2 achieved the highest mean score of 4.26 indicates that students being more alerts when performing practical tasks related to the vehicle charging system., while Item C4 and C5 recorded the lowest mean score of 4.07, which falls within the "Agree" category based on respondents' feedback.

5. DISCUSSION

The findings of this study show that the Advanced Portable ABS Sensor Simulator (APSSS) is an effective tool to improve students' understanding and engagement in learning the Antilock Braking System (ABS). Students reported better comprehension, higher interest, and increased confidence after using the simulator compared to traditional teaching methods. These results are in line with previous studies which highlighted that simulation-based learning can make lessons more interactive, safer, and more efficient.

At the same time, APSSS addresses common issues such as high cost, safety risks, and time consumption when using real vehicles for demonstrations. However, the study has some limitations since it only involved a small group of students from one institution and focused on short-term outcomes. Future research could explore long-term impacts and the potential use of APSSS in other TVET institutions or even commercial applications.

The use of the ADDIE model in guiding the APSSS development process strengthens its educational relevance. By adhering to a structured instructional design framework, this innovation is not merely a technical prototype, but a pedagogically grounded teaching tool. The evaluation phase demonstrates how the APSSS improves learning outcomes, supports safer teaching practices, and optimizes instructional time. This integration of a proven instructional model with a technical solution aligns with TVET transformation goals and promotes best practices in technology-enhanced teaching and learning.

6. SUMMARY

This study developed the Advanced Portable ABS Sensor Simulator (APSSS) as an innovation for teaching the Antilock Braking System (ABS) topic in the SAU10053 Brake System course at TVET institutions. APSSS was created to solve problems in traditional teaching methods such as high costs, large space requirements, and safety risks when using real vehicles.

The simulator combines real ABS components with electronic systems and mobile apps, allowing students to see and understand ABS signals and operations in a more interactive, practical, and safe way. Tests with 27 students showed big improvements in understanding, interest, and practical skills. APSSS also saved teaching time, reduced costs, improved safety, and used less workshop space, making it a sustainable tool that supports TVET and Industry 4.0 goals.

7. CONCLUSION

In conclusion, the APSSS has proven to be an effective and innovative teaching aid for the ABS topic. The findings show that it improves students' understanding, practical skills, safety awareness, and overall engagement in learning.

This tool not only overcomes the weaknesses of traditional teaching methods but also has strong potential to be expanded to other TVET institutions. With further improvement and long-term studies, APSSS can even be commercialized as a standard training tool to prepare more competent and industry-ready automotive graduates

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