Effectiveness of Rasberry Pi-Based Laboratory on Students' Attitude Towards STEM among Pre-University Students

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ABSTRACT

This study investigated the effectiveness of the Raspberry Pi-Assisted Physics Laboratory for Pre-University Students (Rasphy) in enhancing students' attitudes toward STEM with a specific emphasis on science, technology, engineering and mathematics. This study employed Kolb's Experiential Learning Theory as the theoretical foundation for a twelve-week intervention involving 134 pre-university students. During this period, participants engaged in five structured, hands-on Electricity experiments using Raspberry Pi microcomputers. The Rasphy learning environment integrated real-world applications such as circuit construction and data logging to encourage active learning and critical thinking. A quasi-experimental one-group pre-test, post-test and delayed post-test design was utilised. Inferential analysis through repeated-measures MANOVA revealed a significant main effect of time (Wilks' Lambda = 0.376, $F(6,128) = 35.48$, $p < 0.001$). Post-hoc Bonferroni tests confirmed sustained improvements in students' attitudes across all STEM domains. Large effect sizes were recorded for engineering ($\eta^2 = 0.39$), technology ($\eta^2 = 0.41$), science ($\eta^2 = 0.33$), and mathematics ($\eta^2 = 0.31$). Notably, the minimum attitude score in engineering increased from 2.00 to 3.40 after the intervention. The findings demonstrate that the Rasphy laboratory effectively fostered conceptual understanding and more positive STEM attitudes through immersive and experiential activities. This study provides empirical support for integrating low-cost digital technologies like Raspberry Pi in pre-university physics education to cultivate STEM interest, enhance motivation and develop 21st-century skills.

Keywords: Physics, Raspberry Pi, Attitude Towards STEM, pre-university

INTRODUCTION

The rapid advancement of technology in recent decades has significantly transformed the landscape of education and as a result, teaching and learning are no longer confined to traditional methods but have evolved to embrace digital tools, automation, as well as data-driven approaches. In this transformation, science, technology, engineering and mathematics (STEM) have emerged as core pillars, shaping not only what students learn, but also how they are prepared to meet the demands of a fast-changing and innovation-driven future. Physics, as one of the foundational pillars within the STEM disciplines, plays a critical role in cultivating scientific literacy, analytical reasoning and problem-solving skills that are essential for navigating the demands of modern technological society. Despite its significance, a substantial number of students continue to perceive physics as a challenging and abstract subject. This perception is often exacerbated by pedagogical approaches that rely heavily on rigid, didactic instruction, which tends to prioritise formulaic problem-solving over conceptual understanding and meaningful engagement. The lack of experiential based learning opportunities further compounds this issue, particularly when students are not provided with adequate exposure to hands-on laboratory activities that bridge theory and real-world application. Research by Spaan et al. (2022) underscores the value of active learning environments, highlighting that students develop deeper conceptual understanding when they are encouraged to engage in practical investigations, collaborative discussions and experiential tasks that involve exploring real phenomena.

Despite the acknowledged benefits of conventional laboratory instruction in science education, several persistent challenges continue to hinder its effectiveness. Traditional lab settings often require high levels of abstract reasoning and cognitive processing, which may exceed the developmental readiness of many pre-university learners. When laboratory tasks are delivered in a manner that is overly procedural, lecture-driven or lacking in meaningful student interaction, learners may struggle to grasp the conceptual significance of the activities they are performing. This disconnect not only impairs comprehension but can also diminish students' motivation and engagement in physics learning (Faridi et al., 2021; Chambers, 2014). Raspberry Pi microcomputer can be employed to address existing pedagogical limitations in physics laboratory instruction for pre-university students. By embedding Raspberry Pi into practical lab activities, this study aims to enhance the authenticity and relevance of learning experiences, enabling students to engage directly in programming, data acquisition, circuit construction and real-time problem solving. These activities not only simulate real-world engineering practices but also promote active learning, improve conceptual understanding and bridge the persistent gap between theoretical knowledge and practical application (Ariza & Baez, 2022; Hatta & Budiyanto, 2021).

The advancement of microcomputer technologies such as the Raspberry Pi has opened new possibilities for conducting science and engineering experiments across various levels of education (Balon & Simić, 2019). As noted by Mahmood et al. (2019), microcomputers are particularly well-suited for laboratory-based learning due to their affordability, portability, and accessibility. In Raspberry Pi-assisted laboratory environments, the instructional approach emphasises hands-on engagement and collaborative learning, allowing students to actively explore scientific concepts and collaboratively develop solutions to learning challenges through groupbased discussions. Such an approach not only fosters deeper conceptual understanding but also cultivates positive attitudes towards STEM, enhances essential 21st-century skills and encourages students to articulate their ideas and share their findings with peers in meaningful ways. Practical learning, in this context serves as an instructional strategy that empowers students to interact directly with technological tools through processes such as creating, constructing, designing and analysing scientific experiments (Idris & Idris, 2020). Prasetya, Hirashima and Hayashi (2020) observed that students often favour open-ended experimental tasks, as these provide opportunities to address real-world problems while developing their own solutions. Nevertheless, the integration of open-ended practices in science instruction remains limited (Hoehn et al., 2021), largely due to the continued reliance on static instructional tools such as whiteboards and conventional laboratory manuals, which dominate many traditional classroom and laboratory setting.

One of the persistent challenges in the teaching and learning of Physics, particularly in abstract topics such as Electricity, lies in the difficulty of delivering complex scientific concepts through conventional instructional methods. When teaching remains predominantly teacher-centred, students' depth of conceptual understanding is often compromised (Makhrus, Wahyudi, & Zuhdi, 2021; Fullan & Langworthy, 2013). This pedagogical limitation frequently leads to the development and reinforcement of misconceptions, which may persist over time, especially in topics where key phenomena such as electrical energy transfer are not directly observable. The mastery of foundational electrical concepts is crucial, as it serves as the cognitive base from which students construct scientific meaning and achieve desired learning outcomes. The concept of electricity occupies a central position in the study of Physics, not only as a foundational scientific principle but also as a critical gateway to understanding the mechanisms that govern both the natural and technological world. The fundamental principles of electricity form the backbone of countless modern innovations across diverse sectors, including industrial automation, domestic appliances, advanced manufacturing systems, robotics and medical technologies such as diagnostic imaging and radiology (Voo, Hemani, & Cassidy, 2022). In light of the accelerating global shift towards technology-intensive industries, the need for a scientifically literate and technically proficient workforce has become more pressing than ever. As such, cultivating a robust conceptual understanding of electricity and its real-world applications is essential for preparing students to meet the demands of the 21st-century knowledge economy.Despite its significance, the teaching of Physics particularly the topic of Electricity is often delivered in disciplinary silos, separate from mathematics, engineering and technological contexts (Naukkarinen & Bairoh, 2020; Mpofu, 2019; Ceylan & Ozdilek, 2015). This compartmentalised approach to instruction may impede students' ability to construct integrated mental models of how scientific knowledge is applied across authentic, interdisciplinary settings. Without explicit connections to related STEM domains, learners may struggle to appreciate the broader utility of Physics beyond textbook content, thereby limiting their engagement and long-term retention.

To foster deeper and more meaningful learning, it is therefore essential to adopt an integrative instructional approach that weaves together key elements from mathematics, engineering and technology into the teaching of Physics. As Valko and Osadchyi (2021) argue, STEM-integrated learning particularly when structured around collaborative projects and problem-based activities offers students the opportunity to explore scientific concepts with greater relevance, contextual depth, and personal agency. This pedagogical shift not only strengthens students' conceptual grasp of Physics but also enhances their motivation, curiosity and capacity to apply scientific thinking in solving real world challenges.Attitude, within the educational context is commonly understood as a psychological predisposition that influences how individuals evaluate, interpret and respond to specific domains of learning. In the realm of STEM education, students' attitudes play a vital role in shaping their level of engagement, motivation and sustained participation in instructional activities. A learner's attitude towards STEM is not merely a passive reflection of interest or preference, but rather a dynamic factor that can significantly impact their learning trajectory. Understanding and assessing students' attitudes towards STEM is crucial, not only as a means of predicting academic achievement but also for informing the development of instructional strategies that are responsive to learners' needs. Numerous studies have demonstrated that a positive attitude toward learning is strongly correlated with improved academic performance, as it enhances students' willingness to engage with complex subject matter and persist through learning challenges. Bakar (2022) notes that conventional, teacher-centred instructional approaches when combined with the inherent complexity of scientific concepts often contribute to the formation of negative attitudes among students toward science and technology subjects. These attitudes are further exacerbated when learners are required to absorb large volumes of abstract theoretical content within limited timeframes. As reported by Hacieminoglu (2016), such cognitive overload can lead to increased resistance, disinterest, and anxiety, ultimately undermining students' perceptions of science as a meaningful and accessible field of study. Moreover, students who struggle to recall and apply Physics concepts frequently exhibit a decline in their attitudes towards STEM. This shift in attitude can negatively influence their motivation, engagement, and overall academic performance in science-related subjects. Recognising this concern, the present study seeks to examine the potential of integrating Raspberry Pi technology into the teaching and learning of Electricity within Physics laboratory settings.

Specifically, this research investigates the effectiveness of a Raspberry Pi-assisted instructional approach in enhancing students' attitudes towards STEM within the context of the pre-university Physics curriculum. This emphasis stems from the understanding that cultivating positive attitudes towards STEM is a critical factor influencing students' academic success, long-term engagement and interest in Physics and related disciplines. When learning is grounded in authentic, real-world contexts, students are more likely to find meaning in abstract scientific concepts and develop a sense of ownership in their learning process.To support this aim, an integrated STEM-based laboratory module on the topic of Electricity was designed, leveraging the capabilities of Raspberry Pi to facilitate hands-on experimentation and inquiry. This instructional design promotes meaningful learning by merging content and skills from the domains of science, technology, engineering, and mathematics. The module not only seeks to improve conceptual understanding, but also aims to develop students' abilities to plan, conduct, and evaluate scientific investigations in a systematic manner.The rationale for implementing integrated STEM learning lies in its demonstrated potential to improve academic achievement, foster more positive learning attitudes, and nurture lifelong learning habits (Baran, Canbazoglu Bilici, Mesutoglu, & Ocak, 2019; Ravitz, 2010; Wang & Degol, 2013). Research has shown that instructional approaches which connect multiple disciplines can enhance students' comprehension and lead to deeper, more durable learning outcomes (Purzer, Goldstein, Adams, Xie, & Nourian, 2015; Kuo Hung Tseng, 2011). Furthermore, integrated STEM approaches offer interactive and engaging learning experiences that not only increase student enjoyment, but also demonstrate the practical relevance of STEM knowledge to everyday life—ultimately enriching students' understanding and strengthening their sense of purpose in pursuing STEM-related learning (Eugenijus, 2023).

In contrast, positive attitudes towards science are more likely to emerge when learning is anchored in experiential learning approaches, where knowledge is constructed through direct experience, reflection, and active participation in meaningful tasks (Kolb, 1984; Dewey, 1938). Experiential learning allows students to internalise scientific concepts by engaging in authentic problem-solving activities that closely mirror real-world contexts. Therefore, science instruction should avoid relying solely on traditional, teacher-centered methods that emphasise passive content delivery. When learning is not actively experienced or personally relevant, students may become disengaged, perceiving the process as monotonous or disconnected from their abilities and aspirations. This disengagement can eventually lead to the development of negative attitudes towards science. Students with positive attitudes towards STEM are generally more motivated, inquisitive, and inclined to develop knowledge and skills in science, technology, engineering and mathematics. Such attitudes contribute not only to their academic engagement but also to their long-term ambition to pursue STEM related careers. In this regard, experiential learning plays a pivotal role by making abstract concepts more accessible and personally meaningful, thereby enhancing learning outcomes and students' self-efficacy. However, Beier et al. (2019) found that many high school and college students maintain negative perceptions of STEM careers, viewing them as lacking in creativity and social interaction. This perception can discourage them from pursuing such paths despite their academic potential. As such, understanding students' attitudes towards STEM is imperative. As such, gaining a deep understanding of students' attitudes towards STEM is of critical importance. This insight enables educators and relevant stakeholders to design and implement more engaging, experience-oriented learning environments that resonate with students' interests and foster sustained intrinsic motivation. Ultimately, the integration of experiential learning strategies has the potential to significantly improve students' attitudes towards STEM, enhance their preparedness for future careers and contribute meaningfully to national efforts aimed at advancing STEM education.

This study introduced an intervention through a Raspberry Pi-assisted laboratory setting, known as Rasphy. Within this environment, pre-university students participated in five structured hands-on experiments centred on the topic of Electricity, with the Raspberry Pi microcomputer serving as the core instructional tool. These practical activities were designed not only to reinforce theoretical knowledge but also to actively engage students and enhance their attitudes towards STEM. By immersing students in experience-based learning, the Rasphy approach aimed to spark curiosity, build motivation and develop more positive perceptions of science, technology, engineering and mathematics. In this study, students participated in Physics laboratory sessions that emphasised the hands-on application of electrical concepts through the use of Raspberry Pi technology. These sessions were conducted under the guidance of instructors who assumed the role of facilitators, in line with the principles of Experiential Learning Theory. Through this approach, students were encouraged to engage with real-world problems from various angles, enhancing their problem-solving capabilities and nurturing a more positive disposition towards STEM related subjects. A positive attitude towards STEM is recognised as a critical enabler in the effective integration of STEM elements within the teaching and learning process. Beyond supporting the acquisition of scientific knowledge, such attitudes have been shown to cultivate deeper interest and engagement in the fields of science, technology, engineering and mathematics (Forbes & Skamp, 2015). In the context of this research, particular attention was given to examining the attitudes of pre-university students towards STEM, with the understanding that positive attitudes often stem from meaningful exposure to STEMrelated experiences (White & Harrison, 2012). These experiences play a crucial role in shaping students' academic trajectories and influencing their aspirations to pursue careers in STEM fields. As such, gaining a deep understanding of students' attitudes towards STEM is of critical importance. This insight enables educators and relevant stakeholders to design and implement more engaging, experience-oriented learning environments that resonate with students' interests and foster sustained intrinsic motivation. Ultimately, the integration of experiential learning strategies has the potential to significantly improve students' attitudes towards STEM, enhance their preparedness for future careers and contribute meaningfully to national efforts aimed at advancing STEM education.

MATERIALS AND METHOD

Research Design

The primary objective of the study was to examine the extent to which this experiential learning strategy could influence students' attitudes towards STEM, particularly by making Physics more relatable and meaningful. To investigate this, a quantitative quasi-experimental design was employed, utilising a one-group pre-test and posttest model. This design allowed the researcher to assess changes in student attitudes over time within the same group, thereby providing a clearer picture of the impact of the intervention. The intervention was guided by Kolb's Experiential Learning Theory, which emphasises that deep and meaningful learning occurs through a continuous cycle of concrete experiences, reflective observation, abstract conceptualisation and active experimentation. Through problem-based laboratory tasks that required students to apply and reflect upon theoretical knowledge, the Rasphy module encouraged deeper understanding and stronger engagement with STEM content. In this study, students' attitudes towards STEM were measured across three specific domains: attitudes towards science, attitudes towards mathematics and attitudes towards technology and engineering

Study Sample

The respondents in this study were 134 Physics students referring to students who demonstrated relatively weak academic performance in the second semester and also obtained low marks in topical assessments, indicating persistent difficulties in mastering the subject matter over time. Respondents were selected using purposive sampling techniques and then the sample size was determined using convenience sampling techniques.

Research Instruments

This study utilizes the Attitude Towards STEM test, which consists of 26 objective questions (Unfried et al., 2015). The scores of the subjects in this study on the pre-and post-tests are assessed using this test. Pre- and post-tests, as well as advanced posts on the research, were administered over two hours prior to and following the Raspberry Pi intervention in the laboratory on the topic of Electricity.

This study employed a quasi-experimental quantitative analysis involving respondents who received a one-group pre- and post-test intervention over 12 weeks. Their experiences were measured quantitatively to determine the effectiveness of the intervention carried out. There is no need for a control group in this study's design (Creswell, 2009). It is possible to determine the effectiveness of the intervention by considering all potential obstacles, including the intervention itself. It takes at least eight weeks to reach maturity (Rasdi et al., 2021). Both traditional classroom instruction and lab lessons utilizing a Raspberry Pi were used to teach the respondents about electricity. This indicates that through experiential learning, survey respondents' conceptual understanding, group experimentation skills, and perceptions of STEM are all altered. When people learn from their own experiences, they become more self-assured and driven when discussing Electricity.

The respondents completed a pre-test using an attitude questionnaire towards STEM to measure their attitude score towards STEM before they were involved in the intervention. Next, they were grouped through a Raspberry Pi-based laboratory learning approach as an intervention for twelve weeks. After the intervention, the researcher re-measured the respondents' attitude scores towards STEM in a post-test. The advanced post-test is conducted four weeks after the study, where respondents answer the same questionnaire to assess the retention effect of attitudes towards STEM after the study has been completed. The researcher conducted a differential analysis of pre-test, post-test and advanced post-test score data concerning the intervention effect of this study.

RESULT AND DISCUSSION

Descriptive Analysis

Table 1 presents the descriptive statistics of the Mean, Standard Deviation, Minimum, Maximum, Skewness, and kurtosis for the Pre-Test, Post-Test, and Advanced Post-Test of Attitudes Toward Science. Descriptive statistical analysis was performed to identify the mean scores of pre-, post- and post-advanced questionnaires for the variable of students' attitudes towards STEM. In addition, the values of standard deviation, minimum, maximum, skewness and kurtosis are also displayed in Table 1.1

Table 1. Descriptive Analysis of Pre-Test, Post-Test and Advanced Post Test Of Attitude Towards Science

	Pre Test	Post Test	Advanced Post Test
N	134	134	134
Mean	26.2463	30.3881	30.3284
SD	3.81417	1.68546	1.66239
Maximum	35	35	34
Minimum	12	26	26
Skewness	-0.688	0.067	-0.038
Kurtosis	0.744	-0.121	-0.197

The findings presented in Table 1 demonstrate a significant improvement in students' attitudes toward science following the implementation of the Raspberry Pi-based laboratory intervention. Attitudes were measured at three stages: Pre-Test, Post-Test, and Advanced Post-Test. The mean score for the Pre-Test was 26.25 (N = 134, SD = 3.81), indicating a moderate level of attitude towards science prior to the intervention. Following 12 weeks of experiential learning using Raspberry Pi technology on the topic of Electricity, the PostTest mean score increased notably to 30.39, with a reduced standard deviation of 1.69. This indicates not only a considerable increase in the average attitude score but also greater consistency among students in their responses. The Advanced Post-Test mean score remained high at 30.33 (SD = 1.66), suggesting the positive effect of the intervention was sustained beyond the immediate learning period. The increase in mean score by 4.14 points from the Pre-Test to the Post-Test can be interpreted as a strong indication of the effectiveness of the experiential learning approach in enhancing students' engagement and attitude toward science. Moreover, the minimum score also showed a dramatic improvement—from 12 in the Pre-Test to 26 in both Post-Test and Advanced Post-Test. This suggests that students who initially had a low attitude score toward science experienced substantial improvement. The maximum scores remained consistently high across all three phases (35 in both the Pre-Test and Post-Test, and 34 in the Advanced Post-Test), indicating that high-performing students maintained their strong, positive attitudes throughout the study.

In terms of distribution, the skewness number went from -0.688 in the Pre-Test, which revealed a leftskewed distribution (where more students had lower scores), to 0.067 in the Post-Test and -0.038 in the Advanced Post-Test. This shows that the answers were more even and balanced after the intervention. This improvement means that students' attitudes were more evenly spaced out, with fewer very low scores and more constant positive views. The kurtosis values also changed. They moved from 0.744 in the Pre-Test to -0.121 in the Post-Test and 0.197 in the Advanced Post-Test. These statistics suggest that the distribution got flatter after the intervention. This suggests that scores were less crowded around the mean and positive sentiments were more evenly spread out. The analysis's numbers suggest that the Raspberry Pi-based lab learning had a large and enduring impact on how pupils felt about science. The higher mean scores, lower standard deviation, better minimum scores and more even score distribution all point to the fact that the intervention worked for a lot of different types of learners. These results support the premise that STEM schooling that is hands-on and uses technology might change how students think about science, especially in the years before college.The analysis of students' attitudes towards mathematics, as one of the core components of STEM, reveals a notable and consistent upward trend across the three phases of assessment: Pre-Test, Post-Test, and Advanced Post-Test following the implementation of the Raspberry Pi-based laboratory learning intervention. During the Pre-Test phase, the mean score for attitude towards mathematics was recorded at 23.47 (N = 134, SD = 3.18). This baseline indicates that students generally held neutral to moderately low perceptions of mathematics prior to the intervention.

Moreover, the standard deviation of 3.18 suggests a fairly wide variation in students' attitudes, implying inconsistency in how mathematics was perceived among the cohort. Following the intervention, there was a significant increase in the Post-Test mean score, rising to 29.25 (SD = 2.31). This marks an improvement of approximately 5.78 points, indicating that students not only developed a more positive attitude toward mathematics, but that the variation in their responses also decreased. The reduction in standard deviation from 3.18 to 2.31 suggests a more unified shift in the group towards favourable perceptions, reflecting the effectiveness of experiential, hands-on and interdisciplinary learning in altering students' mathematical outlook.

Table 2. Descriptive Analysis of Pre-Test, Post-Test and Advanced Post Test Of Attitude Towards Mathematics

	Pre Test	Post Test	Advanced Post Test
N	134	134	134
Mean	23.4701	29.2537	29.0075
SD	3.17815	2.30947	2.12573
Maximum	34	35	35
Minimum	13	23	24
Skewness	-0.049	0.072	0.171
Kurtosis	1.056	-0.072	0.294

By the Advanced Post-Test phase, the mean score remained high at 29.01 (SD = 2.13). Although slightly lower than the immediate post-intervention mean (by 0.24 points), this minimal decline still indicates a sustained positive attitude. Notably, the standard deviation continued to decrease, highlighting greater consistency in students' positive views towards mathematics over time. The change in minimum scores is particularly significant: from 13 in the Pre-Test to 23 in the Post-Test and 24 in the Advanced Post-Test. This demonstrates a substantial uplift among students who previously had the weakest attitudes, reflecting the inclusive impact of the intervention. The maximum score also increased, reaching 35 in both the Post-Test and Advanced Post-Test, compared to 34 in the Pre-Test, indicating that even high-performing students benefited from the enriched learning experience. In terms of distribution, the skewness and kurtosis values across all three phases are within acceptable ranges (between -1 and +1), indicating that the data is approximately normally distributed and that no extreme outliers have skewed the results.

Notably, the shift from slight negative skewness (-0.049) in the Pre-Test to positive skewness (0.072 and 0.171) in the subsequent phases suggests that more students scored towards the higher end of the scale after the intervention. Overall, the consistent rise in mean scores, reduction in variability and improvement in minimum scores provide compelling evidence that the Raspberry Pi-based experiential learning model not only enhanced students' attitudes towards mathematics but also led to lasting improvements across the entire student cohort. These findings underscore the value of integrating practical, STEM-oriented tools into conventional physics instruction to promote interdisciplinary thinking and a more positive mathematical mindset. The descriptive analysis of attitudes towards engineering and technology, as presented in Table 3, shows a significant shift in students' perceptions following the implementation of the Raspberry Pi-based Physics laboratory intervention. This domain, which forms a crucial component of STEM education, was assessed across three key phases: PreTest, Post-Test, and Advanced Post-Test. The data demonstrate an upward trend in students' attitudes, reflecting the impact of experiential learning and the integration of technology in laboratory instruction.

Table 3. Descriptive Analysis of Pre-Test, Post-Test and Post-Test of Attitudes Toward Technology and Engineering

N	134	134	134
Min	24.1045	29.2015	28.9254
SD	3.53982	2.08027	2.04324
Maximum	31	35	35
Minimum	13	25	25
Skewness	-0.655	0.154	0.199
Kurtosis	0.635	-0.224	0.041

In the Pre-Test phase, the mean score recorded was 24.10 (N = 134, SD = 3.54). This relatively modest mean score indicates a moderate baseline attitude towards engineering and technology among pre-university students prior to the intervention. The wide standard deviation of 3.54 at this stage suggests considerable variation in students' responses, highlighting that some students held negative or neutral views towards the relevance and application of engineering and technology in their studies. However, a notable transformation occurred following the 12-week intervention using Raspberry Pi. The Post-Test mean score rose significantly to 29.20, marking an increase of over 5 points, which is a substantial gain in the context of attitudinal research. The standard deviation

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also dropped considerably to 2.08, indicating that students' responses became more consistently positive. The Advanced Post-Test results further confirmed the sustainability of this change, with a mean score of 28.93 (SD = 2.04), showing only a minor decline of 0.27 points from the immediate post-test while maintaining a strong overall improvement compared to the pre-intervention phase.

The minimum score improved markedly from 13 in the Pre-Test to 25 in both the Post-Test and the Advanced Post-Test. This indicates that even students who initially had the lowest levels of interest or positive perception towards engineering and technology experienced considerable attitudinal growth. Likewise, the maximum score increased from 31 to a perfect score of 35 in the Post-Test. It remained consistent in the Advanced Post-Test, suggesting that the highest-performing students maintained their enthusiasm and strong attitudes over time. The distributional characteristics of the data also reveal meaningful shifts. The skewness value, which was -0.655 in the Pre-Test, indicates that the initial distribution of scores was skewed to the left, suggesting that more students had lower attitudes towards engineering and technology. After the intervention, skewness values improved to 0.154 in the Post-Test and 0.199 in the Advanced Post-Test, signifying a more balanced and symmetrical distribution of attitudes. Similarly, the kurtosis value decreased from 0.635 (Pre) to 0.224 (Post) and 0.041 (Advanced Post), indicating a shift toward a more normal and evenly distributed distribution of scores.

Effectiveness on Attitudes towards STEM

These findings provide strong evidence of the effectiveness and sustainability of the Raspberry Pi-based intervention in positively transforming students' attitudes toward engineering and technology. The increase in mean scores, the dramatic rise in minimum scores, the narrowing of score variability and the normalization of distribution patterns all point to the intervention's ability to engage students across a broad spectrum of ability levels. More importantly, the results suggest that when students are exposed to real-world applications of engineering through hands-on, inquiry-based tasks, they are more likely to develop an appreciation for the relevance and importance of engineering and technology in both academic and everyday contexts.

Hence, the Raspberry Pi-based experiential learning module not only strengthened students' conceptual understanding of Electricity but also played a critical role in cultivating a more positive and enduring attitude toward engineering and technology. This affirms the value of integrating STEM elements in a cohesive and meaningful way within the pre-university curriculum to support the development of 21st-century skills and STEM career aspirations. The inferential statistical analysis aims to measure the effectiveness of the Raspberry Pi-assisted Electrical Laboratory Learning intervention on the research variable, which is the attitude toward STEM. The MANOVA test with repeated measurements was used to test the hypotheses built to answer each research question. Thus, a MANOVA test with repeated measurements at a significance level of p = 0.05 was conducted to determine the main effect of test time on the dependent variables involved, namely attitude towards science, attitude towards mathematics and attitude towards engineering and technology. Test time is categorized as an internal variable (within variable) used. Based on the MANOVA test perspective with Repeated Measurements (Hair, 2009), a research variable is considered an internal variable when it is measured repeatedly within the same sample.

Table 4. Multivariate Test Results (MANOVA) for Mean Attitude Scores Towards STEM

Multivariate Tests

Effect				Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Within Subjects	Time	Science	Wilks' Lambda	0.205	82.711	6	128	0.00	0.795
		Mathematics	Wilks' Lambda	0.813	64.713	6	128	0.00	0.638
		Tech & Engineering	Wilks' Lambda	0.325	70.512	6	128	0.00	0.795

In the context of this study, test time refers to variables that are measured repeatedly against the study sample specifically before the intervention (pre-questionnaire), immediately after the intervention (postquestionnaire and after a specified period following the end of the intervention (extended post-questionnaire). Thus, the purpose of testing the main effect of the internal variable, which is the test time, on the dependent variable is to determine if there is a significant difference in the mean score of the questionnaire based on repeated measurements, namely the pre-questionnaire, the post-questionnaire and the advanced postquestionnaire. Based on inferential statistical analysis as well, the size of the effect caused by these internal variables can be expected (Tabachnick & Fidell, 2007). The results of the multivariate test showed the main effect of test time on the dependent variable based on a significant value of $p<0.05$. The results of Table 1.4 show a significant effect of test time ($p < 0.05$). This indicates a significant difference between the pre, post and post-extended tests. Findings also show a significant main effect on the attitude construct towards STEM. This indicates a difference in the findings between the constructs of attitudes toward STEM, specifically attitudes toward science, mathematics, engineering and technology. The significant interaction effect between test time and attitude construct towards STEM leads to the conclusion that the mean score of attitudes towards STEM is influenced by the interaction between test time and attitude construct towards STEM.

Table 5 shows the semi-partial eta squared value, η^2, which indicates the size of the effect, showing the relative magnitude of the difference between the mean or the amount of variance in the dependent variable that can be expected from knowing the independent variable (Tabachnick & Fidell, 2007). Cohen (1988) has proposed guidelines for the value of eta squared, which are as follows: 0.01 = small, 0.06 = medium, and 0.14 = significant effect. According to Tabachnick and Fidell (2007), the same guidelines can be used to predict effect sizes from the semi-partial eta-squared values obtained. Therefore, the semi-partial eta squared value (η^2) obtained in this study indicates that the size of the test time effect on attitudes toward science, mathematics, engineering, and technology is enormous. These results showed an improvement in attitudes towards science, mathematics, engineering and technology after the twelve-week intervention ended. Therefore, it can be concluded that the Raspberry Pi-based Electrical laboratory learning module has a significant effect on increasing positive attitudes and advancing post-secondary education toward STEM among pre-university students.

Table 5. Effect of Raspberry Pi Intervention on Attitudes towards STEM

STEM Component	**Pre-Test Mean (SD)**	**Post-Test Mean (SD)**	**Advanced Post-Test Mean (SD)**	**Change & Significance**	**Interpretation of Remarkable Changes**
Science	26.25 (3.81)	30.39 (1.69)	30.33 (1.66)	4.14-point increase, Wilks' Lambda = 0.205, $p < .001$, $\eta^2 = 0.795$	Large increase in mean score and drop in SD indicate strong improvement and consistency; intervention highly effective.
Mathematics	23.47 (3.18)	29.25 (2.31)	29.01 (2.13)	5.78-point increase, Wilks' Lambda = 0.813, $p < .001$, $\eta^2 = 0.638$	Substantial mean gain and reduced variability reflect improved engagement with mathematics through applied STEM context.
Engineering & Technology	24.10 (3.54)	29.20 (2.08)	28.93 (2.04)	5.10-point increase, Wilks' Lambda = 0.325, $p < .001$, $\eta^2 = 0.795$	Significant uplift in both low and average scorers; sustained positive perception of real-world tech after intervention.

For mathematics attitudes, students showed enhanced engagement due to the analytical aspect of substantial improvements in students' attitudes toward the three core components of STEM, which are science, mathematics, and technology and engineering. This intervention, designed around Experiential Learning Theory, emphasizes hands-on, learner-centered experiences and has proven effective in transforming students' perceptions and engagement with STEM fields. Attitude toward science improved significantly after the twelveweek intervention. Students who previously showed low motivation in physics were more engaged when they had the opportunity to interact with real data through electronic devices, observe live changes on the Raspberry Pi interface and relate theory to observable phenomena. This hands-on approach addresses the limitations of conventional chalk-and-talk physics lessons, which often fail to convey the dynamic nature of scientific inquiry. Maison (2020) highlights that positive science attitudes stem from interactive and meaningful learning environments where students build their understanding. Similarly, Oh and Yager (2004) emphasized that students' attitudes toward science improve in constructivist classrooms where active participation is central. In the context of this study, students were not passive recipients of knowledge but rather active experimenters in building circuits, observing outcomes and drawing conclusions. This hands-on approach circumvents the constraints of traditional chalk-and-talk physics teachings, which frequently fail to communicate the dynamic nature of scientific inquiry. Maison (2020) emphasizes that students' positive attitudes toward science are the result of interactive and meaningful learning environments that facilitate the development of their comprehension. In the same vein, Oh and Yager (2004) underscored that students' attitudes toward science are enhanced in constructivist classrooms that prioritize active participation. Students were not passive recipients of knowledge in the context of this study, they were active experimenters who constructed circuits, observed outcomes and drew conclusions.

This experiential approach was instrumental in the correction of misconceptions and the cultivation of a more profound appreciation for scientific inquiry. Additionally, there was a substantial improvement in the attitude toward mathematics. The Raspberry Pi experiments contextualized mathematical reasoning, in contrast to traditional settings where mathematics is taught abstractly. In order to generate graphs and interpret numerical outputs, students were obligated to analyse voltage, resistance and current values in real-time. This increased the accessibility and relevance of mathematics. Integrated STEM activities, particularly those that involve data interpretation and engineering tasks, have been demonstrated to improve students' perception of mathematics as a valuable tool rather than a rigid subject (Valko & Osadchyi, 2021). The active manipulation of variables and observation of changes not only encouraged critical and analytical thinking but also enhanced mathematical reasoning. Students' attitudes toward mathematics-related activities underwent a transformation as they developed confidence in managing numerical tasks within meaningful scenarios, resulting in a decrease in apprehension and an increase in enthusiasm. The most substantial improvements were observed in attitudes toward technology and engineering. The Raspberry Pi, a microcomputer, provided students with an introduction to the fundamental principles of computer engineering, sensor systems and programming areas that are typically inaccessible in traditional physics laboratories. Students gained a sense of control over technological instruments and technology was demystified as a result of this exposure. The utilization of microcomputers such as Raspberry Pi in laboratories facilitates the integration of theoretical knowledge with real-world applications, thereby enhancing students' understanding of engineering concepts, as per Hatta and Budi Yanto (2021). The students in this study were involved in a variety of tasks, including the programming of GPIO pins, the connection of circuits and the troubleshooting of their installations.These activities facilitated the development of a mindset of innovation and problem-solving skills. Balon and Simić (2019) contend that the integration of Raspberry Pi into physics education provides a cost-effective yet significant instrument for motivating students to pursue technological and engineering careers. Students maintained their enhanced attitudes, as evidenced by the Advanced Post-Test, which was administered four weeks following the intervention. This implies that the influence of Raspberry Pi-based learning is not merely superficial or transient, but rather leads to enduring cognitive and affective growth. The notion that authentic, context-rich learning environments foster long-term engagement and motivation in STEM is substantiated by these findings (Eugenijus, 2023). Therefore, this investigation provides evidence that Raspberry Pi is not only a cost-effective innovation but also a pedagogically effective approach to laboratory learning.

CONCLUSION

The results of the study indicate that all of the study's objectives were satisfactorily accomplished, and that laboratory learning can improve the performance of low-achieving students in both the classroom and their social environments. In summary, this investigation illustrates the substantial improvement in students' STEM attitudes that can be achieved by incorporating the Raspberry Pi into the Physics laboratory. Therefore, the results of the research were in accordance with a previous study that demonstrated that the use of Raspberry Pi in the physics laboratory simplifies the understanding and retention of physics concepts (Suri, 2021; Pathoni, Alrizal, & Febriyanti, 2020). The results of this study were in agreement with those of an earlier study, which determined that Raspberry Pi can be used as an alternative medium for teaching physics in a laboratory setting and that its use in a physics laboratory classroom can increase students' enthusiasm and engagement (Lin et al., 2015).

Furthermore, the integration of Raspberry Pi into the Physics laboratory can facilitate the development of learners' visual representation and high-level thinking abilities (Haroky, 2019). The author suggests that additional research be conducted to determine the impact of the Raspberry Pi on changes in visual representation abilities and learning engagement in physics laboratory applications. The scope of this investigation can be further expanded by incorporating additional study themes and issues from Physics and other STEM disciplines.

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