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CSR-Driven STEM Education: Case Study on PolyDuino Arduino Kits Implementation in Secondary Schools, Kedah

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Abstract: The persistent challenge in STEM education is the gap between theoretical knowledge and practical application, particularly in underserved communities with limited access to advanced educational tools. This study, conducted as part of a Corporate Social Responsibility (CSR) program, aims to address this issue by evaluating the effectiveness of the PolyDuino Arduino Kit in enhancing STEM education among secondary school students. The study specifically targeted Form 2 and Form 3 students from four selected schools in Kuala Muda and Yan, Kedah districts. An experimental research design was employed, involving approximately 120 students who participated in a series of hands-on workshops facilitated by trained educators. Data were collected through observational assessments and self-reported surveys, focusing on students' engagement, conceptual understanding, problem-solving skills, and collaborative behavior. The findings revealed that 70% of the students demonstrated a strong understanding of the PolyDuino Arduino concepts, with 50% frequently applying their knowledge to create functional projects. Additionally, the study observed significant improvements in student engagement and collaboration, although variations in problem-solving effectiveness were noted. The implications of this study highlight the potential of CSR programs to make substantial contributions to education by providing valuable resources and opportunities for practical learning, particularly in regions with limited access to educational tools. Despite its promising outcomes, the study's limitations include a geographically constrained sample and the short-term nature of the data collection, suggesting the need for future research to explore long-term impacts and broader applicability.

Keywords: *STEM Education, PolyDuino Arduino Kit, Corporate Social Responsibility (CSR), Hands-on Learning, Student Engagement*

1. Introduction and Background

In today's rapidly evolving world, characterized by technological advancements and complex global challenges, the enhancement of Science, Technology, Engineering, and Mathematics (STEM) education has become increasingly crucial. STEM education is vital not only for addressing critical issues such as sustainable development, economic growth, and technological innovation but also for preparing future generations to meet the demands of a digital and knowledge-driven economy. Despite its significance, there are considerable disparities in access to quality STEM education, particularly in developing regions where resources are scarce, and educational infrastructure is often inadequate.

Developing STEM skills is essential for driving innovation, economic growth, and addressing global challenges such as climate change, healthcare, and sustainable energy solutions (Tulivuori, 2021). In Malaysia, this growing emphasis on STEM education is reflected in recent statistics showing increased student interest. According to the Ministry of Education, enrollment in STEM-related courses has risen significantly, with approximately 45% of secondary school students expressing a preference for STEM subjects in 2023 (The Sun, 2023). This rise in interest is driven by various initiatives, including government policies and private sector involvement (Ministry of Science, Technology and Innovation [MOSTI], 2020; Economic Planning Unit, [EPU] 2021). However, challenges remain, particularly in addressing disparities in access to quality STEM education across different regions.

Integrating innovative tools like the PolyDuino Arduino Kits into school curricula represents a progressive step toward bridging this educational gap. These kits offer hands-on experience in robotics and programming, effectively bridging theoretical knowledge with practical skills, enhancing student engagement, and fostering problem-solving abilities. Additionally, Corporate Social Responsibility (CSR) initiatives play a pivotal role in supporting these educational advancements by providing resources and funding to enhance STEM education in underserved communities.

To further support the integration of PolyDuino Arduino Kits in STEM education, past studies offer valuable insights into the impact of robotics kits, particularly within the Arduino cluster. The integration of Arduino kits and robotics into secondary school curricula represents a powerful synergy that enhances STEM education more tangible and accessible to students. This approach not only boosts students' interest in STEM careers but also improves their motivation, achievement, and attitudes toward technology and engineering (Durak, Bilici, & Baran 2023; Ragusa, 2023).

CSR initiatives have emerged as a vital strategy to address these disparities by providing additional resources and support to educational institutions. By leveraging CSR, companies can significantly enhance STEM education, fostering greater student engagement and improving educational outcomes. This case study investigates how CSR initiatives can be effectively employed to advance STEM education, particularly in areas where access to quality education is limited. These initiatives are crucial in preparing students for the demands of the Fourth Industrial Revolution (4IR).

Despite the growing importance of STEM education and the integration of hands-on learning tools like Arduino kits, a noticeable research gap remains in understanding their specific impact within the Malaysian secondary school context. While existing studies have explored the general benefits of educational robotics, limited research exists on how PolyDuino Arduino Kits influence student engagement and learning outcomes in Malaysia.

This study aims to address these gaps by investigating the effectiveness of PolyDuino Arduino Kits in enhancing STEM education and evaluating the contribution of CSR efforts in this context. The primary objectives are: (1) to assess the impact of PolyDuino Arduino Kits on students' STEM skills and engagement, (2) to explore how CSR initiatives support the implementation of these kits, and (3) to provide recommendations for improving STEM education through such collaborations.

2. Literature Review

Stem Education: STEM education, encompassing Science, Technology, Engineering, and Mathematics, is vital for developing a workforce capable of addressing global challenges. Its primary objectives include equipping students with the necessary skills to navigate and contribute to a technology-driven world, addressing complex global issues, and enhancing economic competitiveness. In the modern educational landscape, STEM is essential for cultivating a skilled workforce proficient in leveraging technological advancements and scientific knowledge (Atibuni, Manyiraho & Nabitula 2022; Feng & Hou, 2023).

Globally, trends in STEM education emphasize increasing accessibility and engagement through innovative teaching methods and technology integration. Robotics, coding, and project-based learning are becoming more prevalent, highlighting the practical applications of STEM concepts. Many countries are investing in educational reforms to improve STEM outcomes and address skill shortages in critical industries (Kelley & Knowles, 2016; EPU, 2021; Zhan et al., 2024).

In Malaysia, STEM education is gaining momentum as part of a national strategy to enhance workforce skills and drive economic growth. There is an increasing interest in STEM fields among students, supported by government policies promoting STEM initiatives (MOSTI, 2020; EPU, 2021). However, disparities in access to quality STEM education remain, particularly in rural and underserved areas (Aspin et al., 2022; Idris et al., 2023).

Arduino Robotics Kits: To address these challenges, innovative approaches are essential. Integrating technology like Arduino robotics kits into the curriculum can offer hands-on learning experiences that bridge theoretical knowledge with practical skills. Such tools can enhance student engagement, foster problem-solving abilities, and better prepare students for future careers in STEM fields (Plaza et al., 2018; Karaahmetoğlu & Korkmaz, 2019; Güven, et al., 2022).

Arduino kits, open-source electronics platforms (Darnita, Discrise, & Toyib, 2021; Kondaveeti et al., 2021), enable students to create interactive projects that blend hardware and software, bridging the gap between theoretical knowledge and practical application. Robotics, an interdisciplinary branch of STEM, involves designing, constructing, and operating robots, often utilizing Arduino as a key component. Programming acts as the glue that binds these elements, allowing students to control and automate their projects, thereby fostering computational thinking and problem-solving skills (Edward, 2023).

In Malaysia, this synergy is particularly relevant due to the country's growing emphasis on preparing students for the Fourth Industrial Revolution (4IR) (EPU, 2021). Integrating Arduino kits and robotics into STEM education enables students to engage in hands-on learning, develop critical thinking skills, and gain practical experience in technology-driven fields. These tools can enhance student engagement, foster problem-solving abilities, and better prepare students for future careers in STEM fields (Plaza et al., 2018; Karaahmetoğlu & Korkmaz, 2019; Güven, et al., 2022). Research shows that these experiential learning tools improve engagement and retention of STEM concepts among secondary school students (Arpaci, Kaya, & Bahari, 2023; Selcuk, Kucuk, & Sisman, 2024).

Relevant Theories in STEM Education: The integration of Arduino kits, robotics, and programming in STEM education is supported by several educational theories, including Constructivist Theory, Experiential Learning Theory, Constructionism, and Social Learning Theory. Constructivist theory, championed by Piaget and Vygotsky, emphasizes that learners construct knowledge through experiences and interactions with the world. This theory is applied in STEM education through hands-on activities, such as Arduino projects and robotics, where students actively engage in problem-solving and experimentation. Research by Martínez and Stager (2019) highlights how constructivist principles are utilized in maker education, where tools like Arduino kits facilitate learning through creating, designing, and making.

Experiential Learning Theory, developed by David Kolb, posits that learning is a process where knowledge is created through the transformation of experience. This theory supports the use of Arduino kits and robotics in STEM education, as these tools offer students opportunities to learn through direct experience and reflection. Few studies have demonstrated that students engaged in robotics projects exhibited improved problem-solving skills and a deeper understanding of STEM concepts, aligning with Kolb's model of learning by doing (Papas et al., 2020; Long, Yen, & Hanh, 2020; Zainal et al., 2018).

Constructionism, introduced by Seymour Papert, is closely related to constructivism but emphasizes the creation of tangible artifacts as a way of learning. This theory is particularly relevant to STEM education involving Arduino kits and robotics, as students not only engage in learning but also produce functional projects, solidifying their understanding. A study by Blikstein (2018) explored the effectiveness of constructionist approaches in education and found that students who engaged in Arduino-based projects showed enhanced creativity and critical thinking skills.

Bandura's Social Learning Theory suggests that people learn from one another through observation, imitation, and modelling (Nabavi, 2012). In the context of STEM education, robotics and programming activities can foster collaborative learning environments where students learn from peers and mentors. Research by Barker and Ansorge (2017) showed that when students worked together on robotics projects, they developed not only technical skills but also social and communication skills, highlighting the value of collaborative learning in STEM education.

PolyDuino Arduino Kits: In addition to these established theories, the introduction of PolyDuino Arduino Kits represents a significant advancement in educational technology. PolyDuino Arduino Kits are designed to be more accessible and user-friendly, making them ideal tools for secondary school students. They offer enhanced features such as modular components and simplified programming interfaces, which lower the barrier to entry for beginners while still providing advanced functionalities for more experienced users. This development aligns with Malaysia's educational goals by making STEM education more inclusive and effective.

Despite the recognized benefits of integrating Arduino kits, robotics, and programming into STEM education, there is a noticeable gap in research specifically focusing on their impact within the Malaysian secondary school context. While international studies have demonstrated improved engagement, retention, and understanding of STEM concepts through these tools, there is limited empirical evidence on how these technologies influence Malaysian students' learning outcomes. Moreover, the effectiveness of newer innovations like PolyDuino kits has not been thoroughly explored.

To address these gaps, future research should focus on comprehensive studies within Malaysian schools to evaluate the specific impacts of these tools on student engagement and achievement. Additionally, research should explore how CSR initiatives can further support the implementation of such technologies, particularly in underserved regions. By filling these gaps, educators and policymakers can better understand how to leverage these synergies to enhance STEM education in Malaysia, ultimately preparing students for the challenges and opportunities of the 4IR.

3. Methodology

This study adopts a quasi-experimental research design to comprehensively evaluate the effectiveness of the PolyDuino Arduino Kit in enhancing STEM education among secondary school students. The research targets Form 2 and Form 3 students from four selected secondary schools in the districts of Kuala Muda and Yan, Kedah. The study includes approximately 120 students and 10 trainers and facilitators. These trainers and facilitators are lecturers from Politeknik Tuanku Sultanah Bahiyah Kulim, Kedah.

The CSR program was carried out over two months, from July to August 2023. Data collection was primarily conducted through questionnaires administered to trainers and facilitators. The questionnaires were designed to capture various dimensions of the student's experiences with the PolyDuino Arduino Kit, including their engagement, perceived effectiveness of the kit, and programming skills.

The descriptive statistics applied to the collected data offered a comprehensive overview of student performance across these critical dimensions, guiding further instructional strategies and interventions.

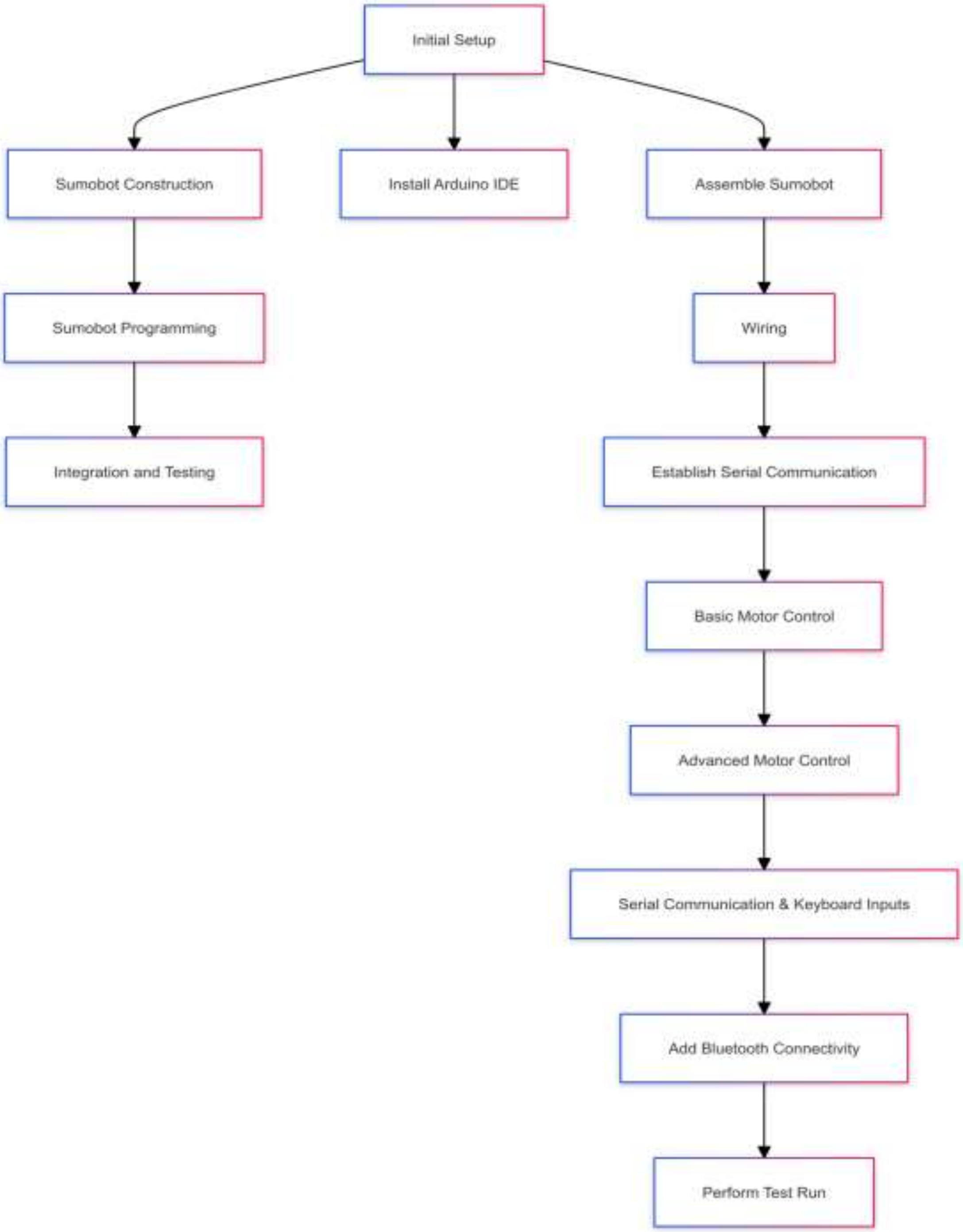
Module: The methodology for this community service program, which utilizes the PolyDuino Arduino Kit, involves a structured approach to introducing and guiding students through the construction and programming of an ESP32-based Sumobot. The module is designed to serve as a practical reference for students, enabling them to gain hands-on experience with robotics and programming within the context of 4IR-focused TVET training. Further details on the PolyDuino Arduino Kit can be seen in Jamiaan and Mohd Adam (2023).

The process begins with setting up the necessary tools, which involves installing the Arduino software and assembling the Sumobot. This assembly phase is broken down into several essential tasks: physically constructing the Sumobot, establishing wiring and connections, and using the Arduino Serial Function to display data on a computer through serial communication.

Once the Sumobot is built, the focus shifts to programming. Students start by learning motor control, which includes managing the direction and speed of the motors. They then advance to integrating motor control with keyboard inputs, allowing them to manipulate motor functions through serial communication.

The final phase combines programming with hardware and introduces Bluetooth connectivity. Students are tasked with integrating their code with the physical robot, ensuring that the programming effectively controls the hardware. This stage culminates in a test run where students assess the performance of their robot and make necessary adjustments to optimize its functionality.

Figure 1: Flow process constructing and programming the ESP32-based Sumobot using the PolyDuino Arduino Kit



Data Analysis: This study employed a primarily descriptive approach, focusing on qualitative observations gathered from a sample of 10 facilitators. These facilitators provided insights regarding student engagement during the Polyduino Arduino robotic project. Due to the small sample size (n=10), the use of inferential statistical tests was not deemed appropriate, as smaller datasets tend to exhibit higher variability, which can compromise the reliability of statistical results. As discussed by Field (2013) and Maxwell & Delaney (2004), such variability can increase the risk of drawing inaccurate conclusions from inferential analyses.

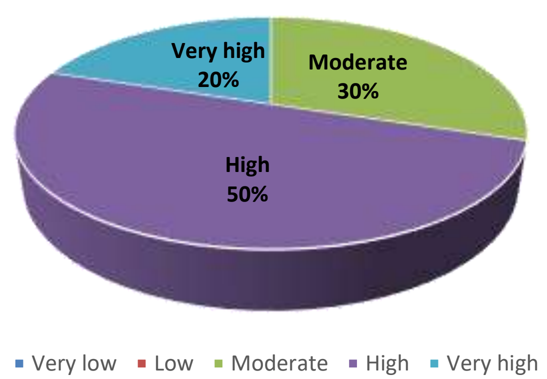
In alignment with previous research by Kim et al. (2017) and Aggarwal & Ranganathan (2019), descriptive studies are often utilized to capture real-world phenomena where qualitative understanding is prioritized over inferential statistical outcomes. Descriptive research, as highlighted by Bulbulia et al. (2019), allows for a deep exploration of specific contexts without overstating findings through inferential methods. For this study, descriptive analysis was chosen to sufficiently capture the nuances of the facilitators' observations regarding student engagement, thereby providing valuable insights into the learning environment without the need for inferential generalizations.

4. Results and Findings

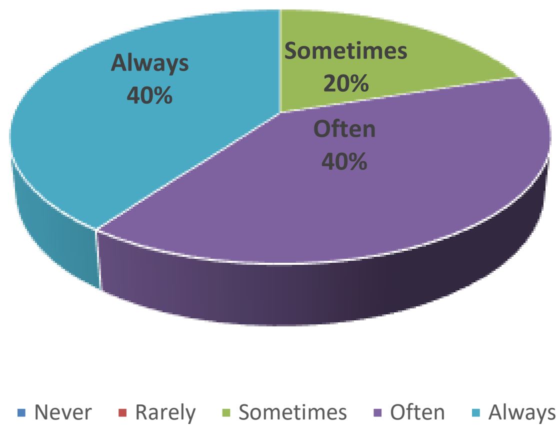
The assessment of student performance was categorized into three key evaluation levels: Engagement Level, Interest and Motivation, and Understanding and Application. Data were collected through observations noted by trainers and facilitators and analyzed using descriptive statistical methods derived from respondent survey forms.

Student Engagement of the PolyDuino Arduino projects: Figure 2 displays the observation from trainers and facilitators on student engagement toward PolyDuino Arduino projects. The engagement involved students' ability to maintain focus during the construction of robotic activities, students' ability to follow instructions without getting easily distracted, students' participation in discussions and problem-solving during the sessions, and student initiative in exploring additional features or functionalities in their PolyDuino Arduino projects.

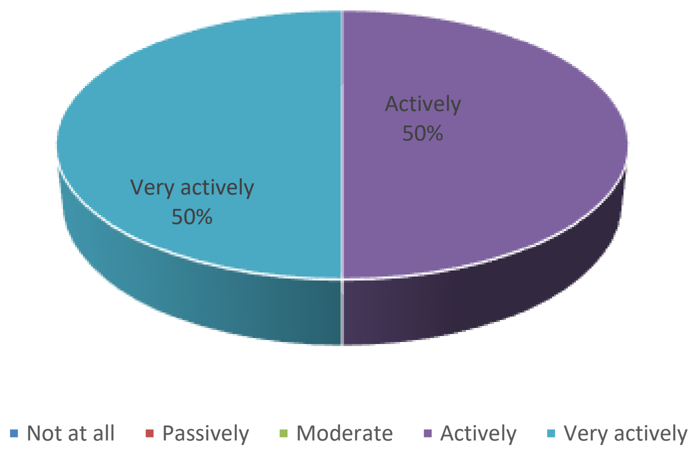
Figure 2: Observation of student engagement toward PolyDuino Arduino projects.



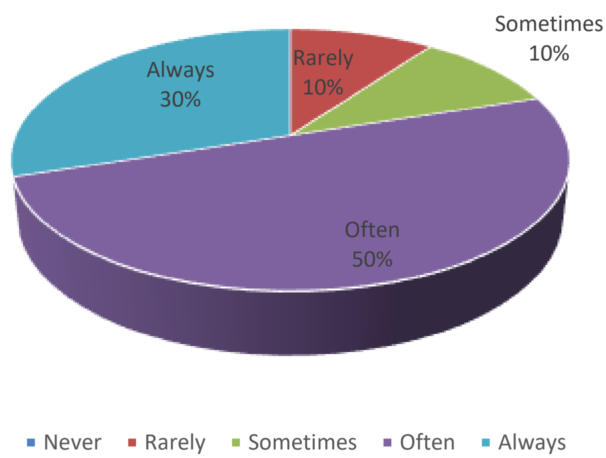
(a) students' ability to maintain focus during the construction activities



(b) Ability to follow instructions without getting distracted



(c) Actively participate in discussions and problem-solving session



(d) Initiative to explore additional features or functionalities

The data in **Figure 2(a)** reveals that a significant majority of students demonstrated a high level of focus during the Arduino construction activities. Specifically, 50% of the participants were rated as having a "High" focus, while 20% exhibited a "Very High" level of concentration. Conversely, 30% of the students were rated as having a "Moderate" focus level. This suggests that while most students were deeply engaged during the construction tasks, a small portion displayed only moderate engagement.

According to **Figure 2(b)**, the ability of students to follow instructions without getting distracted varied, with 40% of students frequently ("Often") adhering to the instructions without distraction, and another 40% consistently doing so ("Always"). However, 20% of the students were observed to "Sometimes" follow instructions effectively. These results highlight that while the majority of students were successful in following the guidance provided, a minority still faced challenges in maintaining focus on the instructions.

Figure 2(c) illustrates that half of the students participated actively in discussions and problem-solving sessions, with 50% categorized as "Very Actively" engaged. The remaining 50% were classified as "Actively" participating. This even distribution indicates that all students were engaged in these collaborative activities, though to varying degrees.

Further observation of the engagement criteria dives into the frequency of students taking the initiative in exploring additional features or functionalities in PolyDuino Arduino projects. The results are shown graphically in **Figure 2(d)**. Specifically, 50% of the students "Often" took the initiative, indicating a strong tendency among half of the participants to engage further with the project beyond the basic requirements. These results suggest that while the majority of students were highly proactive in exploring additional features, there remains a small group that could benefit from further encouragement and support to fully engage with the potential of the PolyDuino Arduino platform.

Students' Interest and Motivation for the Project: In this study, the data on student enthusiasm and persistence during project construction was analyzed to gauge their engagement and problem-solving skills. The results are displayed in **Table 1**. Observational data from trainers and facilitators reveal that all participants demonstrated notable enthusiasm: 50% frequently showed excitement, and the remaining 50% consistently displayed very high levels of excitement throughout the project.

Table 1: Levels of Student Enthusiasm in Project Completion

Did you notice any students expressing excitement or enthusiasm about completing their projects?	Never	Rarely	Occasionally	Often	Very often
Percentage (%)	0	0	0	50.0	50.0

The assessment of student persistence in overcoming challenges during project construction was obtained from observations by trainers and facilitators with the findings quantitatively summarized in **Table 2**. The data revealed that 40% of the students demonstrated moderate persistence, occasionally engaging with the problem-solving required. A majority, 50%, showed a very high level of persistence, frequently tackling project challenges effectively. Additionally, 10% of the students consistently displayed extreme persistence, underscoring their exceptional dedication to overcoming obstacles. The data indicate that a significant majority of students displayed a robust level of determination and commitment, crucial for the successful completion of projects and the development of practical skills in an academic setting.

Table 2: Levels of Student Persistence in Overcoming Project Construction Challenges

How persistent were the students in overcoming challenges or difficulties encountered during the construction?	Not persistent	Slightly persistent	Moderately persistent	Very persistent	Extremely persistent
Percentage (%)	0	0	40.0	50.0	10.0

From this CSR program, we intend to evaluate collaborative behaviors among students during project activities, with a specific emphasis on their propensity to seek assistance or collaborate when faced with challenges. The analysis displayed in **Table 3** reveals that the majority of students consistently collaborated with their peers or sought assistance (60%). Meanwhile, 40% of students frequently sought help or engaged in collaborative efforts during challenging tasks. The results demonstrate significant peer interaction and cooperation, with most students exhibiting strong collaborative skills. Such active engagement indicates that students are eager and proactive in seeking assistance, underscoring the effectiveness of the CSR program in creating a dynamic and supportive educational environment.

Table 3: Frequency of Student Collaboration with Peers During Challenges

Did students seek help or collaborate with **peers** when facing difficulties?	Never	Rarely	Sometimes	Often	Always
Percentage (%)	0	0	0	40.0	60.0

Table 4 assesses the frequency with which students sought assistance from trainers during challenging scenarios. The data reveal that all students engaged with trainers to overcome difficulties, with no instances of students neglecting to seek help. Specifically, 50% of the students often sought help, while the other 50% always sought assistance during challenges.

This shows that the students consistently relied on trainers' support and the other half frequently sought guidance, highlighting the critical role of trainer availability and responsiveness in educational settings. The absence of categories such as 'Never,' 'Rarely,' and 'Sometimes' may reflect a culture of proactive engagement within the learning environment, suggesting that students feel fully supported in seeking help as needed.

Table 4: Frequency of Students Seek Help from Trainers During Challenges

Did students seek help or collaborate with **trainers** when facing difficulties?	Never	Rarely	Sometimes	Often	Always
Percentage (%)	0	0	0	50.0	50.0

The evaluation of student interest in the PolyDuino Arduino construction process, process revealed pronounced enthusiasm. According to trainers and facilitators, which are detailed in **Table 5**, 80% of students displayed very high interest, while 20% showed extreme interest in the construction activities. This distribution underscores a robust engagement across the cohort, highlighting the success of the educational initiative in captivating student interest effectively.

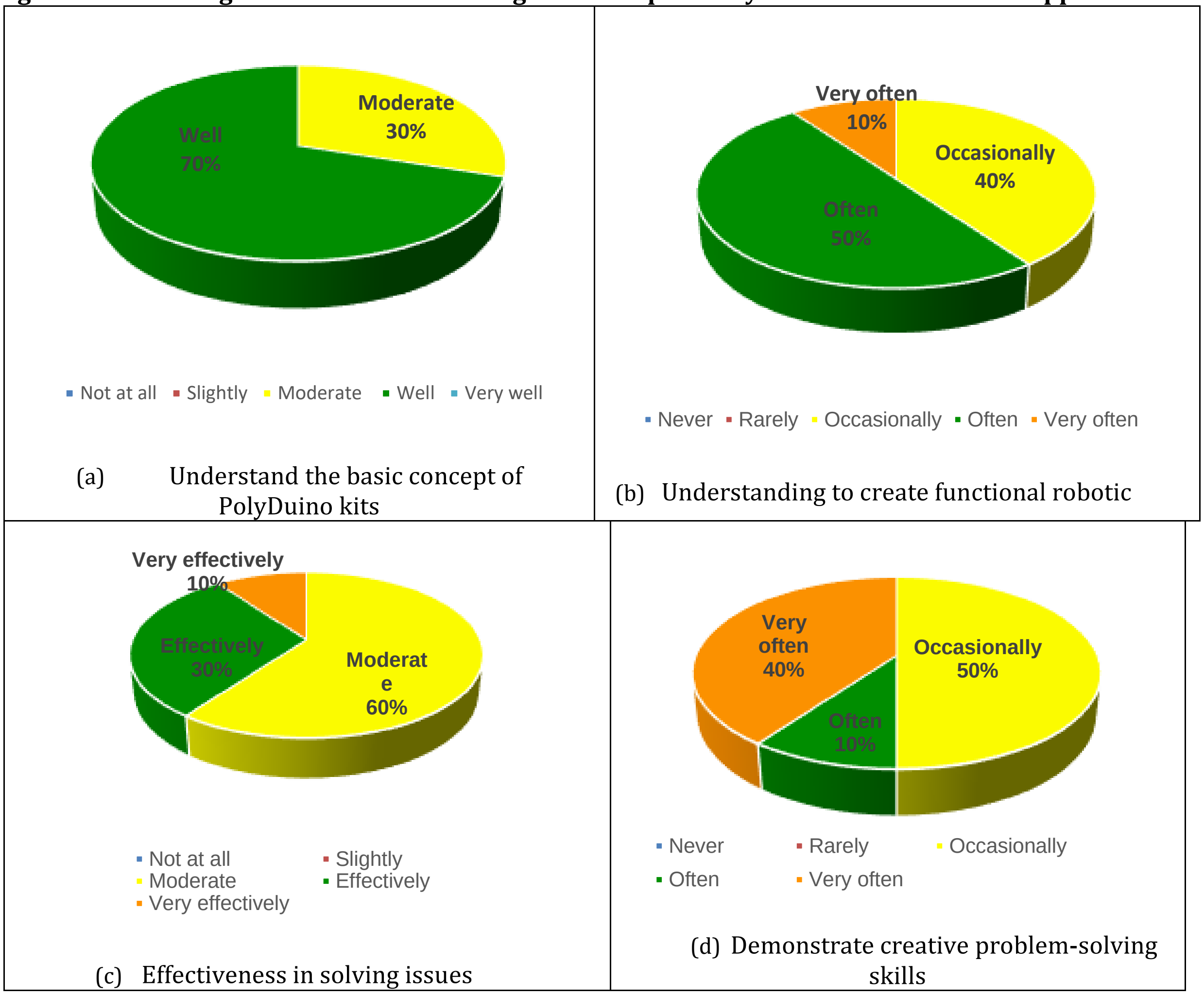
Table 5: Levels of Student Interest in PolyDuino Arduino Construction Process

How interested did the students appear in the overall PolyDuino Arduino construction process?	Not interested	Slightly interested	Moderately interested	Very interested	Extremely interested
Percentage (%)	0	0	0	80.0	20.0

Students Understanding of the Project

Results illustrated in **Figure 3** show descriptive statistics on understanding the concept of PolyDuino Arduino and its application among students.

Figure 3: Evaluating Students Understanding the Concept of PolyDuino Arduino and its Application



(a) Understand the basic concept of PolyDuino kits

(b) Understanding to create functional robotic

(c) Effectiveness in solving issues

(d) Demonstrate creative problem-solving skills

The evaluation of student's understanding of the basic concepts of PolyDuino Arduino reveals that the majority of the students have a strong grasp of the material. Based on the pie chart in **Figure 3(a)**, 70% of the students indicated that they understood the concepts well, while 30% reported a moderate understanding. This suggests that the instructional approach, which likely involved a combination of hands-on learning and theoretical instruction, was effective for the majority of the students. However, students who only achieved a moderate understanding highlight the need for differentiated instruction. These students might benefit from additional resources, such as more practical exercises, peer-assisted learning, or supplemental tutorials, to reinforce their comprehension.

The evaluation of student's ability to apply their understanding to create functional robotic projects indicates a diverse level of engagement and success. **Figure 3(b)** illustrated in the attached pie chart indicates that 50% of the students were able to apply their knowledge often to create functional robotic projects, while 40% did so occasionally. Additionally, 10% of the students reported that they were very often able to create functional projects. The results demonstrate that the majority of students were able to effectively apply their theoretical knowledge to practical, hands-on robotic projects.

The assessment of how effectively students were able to troubleshoot and solve issues during their projects indicates varying levels of success as displayed in **Figure 3(c)**. According to the pie chart, 60% of the students reported that they were able to troubleshoot and solve issues moderately effectively. Meanwhile, 30% of the students indicated that they could troubleshoot effectively, and 10% noted that they were very effective in resolving problems. These results may indicate that students reporting with moderate effectiveness are somewhat capable of handling problems as they arise. The students who reported effective troubleshooting skills likely benefited from a strong understanding of the project materials, which enabled them to address issues more efficiently.

The assessment of students' demonstration of creative problem-solving skills during their projects reveals varying degrees of frequency in applying these skills are shown in **Figure 3(d)**. From the pie chart, 50% of students occasionally demonstrated creative problem-solving abilities, while 40% did so very often. A smaller percentage, 10%, often applied creative problem-solving techniques. This distribution suggests that while a majority of students did engage in creative problem-solving, the frequency of its application varied significantly among them.

The finding may indicate students engaged in creative problem-solving at least occasionally or more frequently suggesting that the projects provided adequate opportunities for students to think critically and innovate. Students who very often utilized creative problem-solving likely benefitted from either a stronger background in project-based learning or from an environment that encouraged experimentation.

5. Conclusion and Recommendations

This study examined the effectiveness of the Polyduino Arduino Kit in enhancing stem education among secondary school students. The results revealed that most students demonstrated a strong understanding of the concepts, with 70% of students showing a high level of comprehension. Additionally, the study highlighted students' ability to apply theoretical knowledge in practical settings, with 50% frequently creating functional robotic projects. The analysis also indicated that while most students were capable of troubleshooting and solving issues, there was variability in their effectiveness, suggesting room for improvement in problem-solving skills.

The findings contribute to the growing body of research on the integration of hands-on learning tools in stem education. The successful application of theoretical knowledge to practical tasks reinforces the constructivist theory, which posits that learners construct knowledge through experience. Moreover, the study supports the notion that problem-based and project-based learning can effectively enhance students' engagement and understanding in STEM fields.

From a practical perspective, the study demonstrates the value of incorporating tools like the Polyduino Arduino Kit in secondary education. These tools not only enhance student engagement but also improve their practical skills, which are crucial for success in STEM careers. Educators are encouraged to adopt similar hands-on learning approaches to bridge the gap between theoretical concepts and real-world applications. While the study provides valuable insights, it is not without limitations. The research was conducted in a limited number of schools within a specific region, which may affect the generalizability of the findings. Additionally, the reliance on self-reported data from students could introduce bias, as students might overestimate or underestimate their understanding and abilities. The study also focused primarily on short-term outcomes, leaving long-term impacts unexplored.

Future research should aim to expand the scope of the study by including a more diverse sample of schools from different regions. Longitudinal studies could also be conducted to assess the long-term effects of using tools like the PolyDuino Arduino Kit on students' academic performance and career choices. Additionally, exploring the impact of differentiated instruction and additional support for students with moderate understanding could provide further insights into improving STEM education outcomes.

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