

Hybrid Teacher Training in Arduino-based Science Education across Different Modalities

Lia Laela Sarah^{1*}, Greg Shaw², Andi Suhandi^{1*}, Ida Kaniawati¹, Mubiar Agustin³

¹Department of Science Education, Universitas Pendidikan Indonesia, Indonesia, ²College of Education, Charles Darwin University, Casuarina NT, Australia, ³Department of Early Childhood Education, Universitas Pendidikan Indonesia, Indonesia

*Corresponding Authors: lialaesa@upi.edu; andi_sh@upi.edu

ABSTRACT

In science education, educators frequently encounter the challenges of inadequate resources, equipment, and pedagogical strategies when planning and executing science projects in classrooms. To address this pervasive issue, forty-one science teachers participated in a training workshop to acquire expertise using Arduino microcontrollers and sensors as instrumental tools for scientific educational experiments. Of the participants, 18 engaged in face-to-face instruction, while others embraced online learning through synchronous platforms, such as Zoom, and asynchronous media, such as Google Classroom. The training consisted of three sections, including science pedagogy and the Arduino context for each session. To evaluate the training results, science teacher participants had to complete the assignment in the pedagogical context and the Arduino science project. Our findings illuminate a disparity in completion rates between online and face-to-face modes of instruction, with 41% of teachers succeeding in the former and a notably higher 79% in the online form. This study underscores the nuanced challenges encountered when incorporating teaching tools into science education activities, irrespective of the instructional mode. The challenges that participants faced included effective translation of wiring diagrams to physical circuits, resolution of coding errors, mitigation of connectivity issues between the Arduino equipment and computers, and challenges in structuring instructional steps that are essential for the successful implementation of Arduino-based science teaching. Nevertheless, 85% of educators expressed a shared perspective on the viability of Arduino tools as instruments for enriching the landscape of science education.

KEY WORDS: Teacher training, Scientific experiments, Hybrid training, Arduino-based learning, Web-based platform

INTRODUCTION

Educators frequently employ audio-visual aids and instructional tools to facilitate student learning. These approaches are particularly prevalent in science education because science instructors employ various strategies to create conducive learning environments, in which students can acquire scientific principles, theories, and practical applications (Smith, 2019). However, any tools to support learning must align with the appropriate pedagogical approaches. Modern education transcends the transmission of knowledge and information. With knowledge growing exponentially, education's goal extends beyond acquiring all subject-related information during school years. Contemporary education should equip students with a lifelong learning journey that begins in school but extends throughout their lives. In a world marked by rapid technological advancement and information proliferation, teachers must exhibit innovation, adaptability, and commitment to supporting students' learning with and about digital technologies.

Simply delivering information is an inadequate strategy for promoting meaningful learning in the current educational landscape. The Internet provides ubiquitous access to a vast repository of information via various devices. Consequently,

education is no longer centered solely on accumulating information but encompasses teaching students how to access, evaluate, and apply information from sources such as the Internet in their daily lives, preparing them for the complexities of the modern world (Reaves, 2019).

In a world characterized by dynamic change, individuals are more likely to change jobs throughout their working lives than ever before. Workplaces are evolving with new skills and ideas continually reshaping job requirements and competition. To equip students with this competitive landscape, it is incumbent upon all schools and educators, including those in the field of science education, to instill 21st-century skills, such as critical thinking, problem-solving, innovation and creativity, and communication and collaboration skills (Johnson, 2021).

Furthermore, schools and educators have witnessed the proliferation of technology use in the facilitation of learning. Integrating Internet-based resources and tools, including online teaching, has become commonplace in various educational contexts (Brown and White, 2019). Platforms such as Google Sites have emerged as free and versatile tools for organizing online classes, developing curricula, and sharing learning resources (Deng and Tavares, 2015). These electronic and paperless resources offer a viable avenue for enhancing

learning experiences and promoting learner engagement in online education (Smith et al., 2022).

The interrelationship between science and technology education standards is emphasized by the National Research Council (1996). These two fields are intricately connected and often synergize to enhance students' educational experiences. For instance, when students actively participate in problem-solving through project design and implementation, they engage in both technology design and project execution, which fosters a deeper comprehension of the scientific and technological aspects involved (Honey and Kanter, 2013). This integrative approach to learning cultivates reflexive problem-solving skills and nurtures essential 21st-century competencies.

Furthermore, it is noteworthy that grasping fundamental science principles frequently goes hand-in-hand with the development of a corresponding understanding of technology (NRC, 2012). This symbiotic relationship between science and technology education enriches students' knowledge and equips them with a holistic perspective, aligning them with the evolving demands of contemporary education (Johnson and Smith, 2020).

Frequently, technologies are intricate and costly, presenting a challenge for science educators seeking accessible and affordable teaching aid (Smith and Johnson, 2020). Arduino, a company specializing in developing, producing, and supporting electronic devices and software, addresses this issue by offering inexpensive, user-friendly solutions. Their products empower individuals worldwide, especially in developing contexts, to access and utilize technologies that interface with the physical world as practical educational tools. Arduino's offerings are characterized by their simplicity, ease of use, and robust functionality, making them ideally suited to meet the needs of educators and students alike (Kotseva et al., 2019).

A science project employing an Arduino microcontroller positively enhances learning effectiveness (Sarah, 2021). Similarly, other research described the use of Arduino technologies in practical activities, highlighting the facilitation of 21st-century skills in learners, particularly design thinking, science, technology, engineering, mathematics (STEM) literacy, and problem-solving (Dat et al., 2024).

Arduino equipment is an accessible and cost-effective option in Indonesia, benefitting from an established and active online community of users (Smith and Johnson, 2020). Arduino microcontrollers and their associated equipment offer flexibility and adaptability, allowing integration with various types of sensors. Nevertheless, integrating technology, especially the latest digital technologies, into the learning process remains challenging for educators, which is particularly pronounced in developing contexts in which access to such technologies may be limited or expensive (Sundeen and Sundeen, 2013). Educators often grapple with deficiencies in the knowledge and skills required for effectively utilizing digital technologies for educational purposes (Haleem et al., 2022). These include

insufficient institutional support, trust, and access to adequate equipment.

A professional development project for science teachers was established to address these challenges and to explore potential solutions. This initiative aimed to empower selected science teachers with the knowledge and practical skills required to effectively utilize Arduino equipment in their teaching endeavors. A pivotal aspect of this project involved the procurement of Arduino equipment and the design and execution of a comprehensive training program, equipping teachers with the expertise required to incorporate this technology into their science teaching.

In this program, a robust online learning environment tailored to cater to the specific learning requirements of teachers was created. To facilitate this, the capabilities of platforms such as Google Classroom were harnessed, and a dedicated site was supplemented by open-source tools. These resources were meticulously curated to provide comprehensive guidelines and instructional materials on utilizing Arduino equipment and adopting pedagogically sound approaches within the realm of science education.

The selection of a platform, such as a site, was deliberate, as it offered a practical avenue for delivering substantive learning experiences while elevating learner engagement with educational content, especially within online learning (Sarah et al., 2022). Drawing from experiences and findings, this paper explores the challenges and successes encountered during this hybrid teacher training program centered around Web-Arduino integration within science projects.

1. How successfully do teachers complete the Web-Arduino training program?
2. What challenges do teachers encounter when implementing Arduino-based learning with different instructional modalities (online and face-to-face)?

THEORETICAL FRAMEWORK

Hybrid Training

Teachers' professional development programs through continuous training are essential to effectively address contemporary educational demands. Teaching is challenging because of teachers' many responsibilities, including the classroom and schedule, lesson planning, materials, and resource production, and sourcing and constructing effective A/V aids and resources. Teachers generally do not have much time for professional development (Mason et al., 2019). To address this issue, our teacher professional development model incorporated a hybrid approach. Professional development in the hybrid mode uses combined online and face-to-face modalities. Course modalities are categorized by Shaw and Northedge (2018), as shown in Table 1.

In the hybrid mode of instruction, online content typically ranges from 30% to 79%. The online discussions were conducted in conjunction with face-to-face meetings.

Online instruction encompasses various dissemination methods, including blogs, podcasts, forums, chat rooms, and videoconferencing. However, the defining feature is the availability of educational materials on the Internet, which offers learners convenient access to resources. These resources take various forms, such as instructional texts and video lectures (Shaw and Northedge, 2018).

One notable advantage of online instruction is its flexibility in terms of both time and place, which provides learners with easy access to convenient resources (Garrison and Kanuka, 2004). However, it is essential to acknowledge that successful participation in all aspects of online training hinges on participants' Internet connectivity and digital literacy levels (Shaw and Northedge, 2018). Some learners may possess high digital competence and confidence, whereas others may require guidance and support when navigating new technology or software (Shaw, 2011).

Hybrid teaching is a valuable and effective alternative mode that caters to participants who attend both face-to-face and online sessions. This approach combines synchronous and asynchronous elements, often facilitated through a Learning Management System (LMS), such as Google Classroom. Well-structured hybrid meetings can harness the advantages of face-to-face interactions while accommodating virtual participation despite the distinct communication dynamics between participants (Ellis et al., 2022). For a comprehensive exploration of the potential benefits and challenges of hybrid meetings, refer to Table 2.

Table 1: Type of course (Shaw and Northedge, 2018)

Content delivered online (%)	Type of course	Typical description
0	Traditional	Course is presented in writing or orally without online technology
1–29	Web facilitated	Course uses web-based technology to facilitate a face to face course
30–79	Blended/Hybrid	Course that is a combine of the online and face to face. Significant proportion of the content is delivered online, uses online discussions, and face to face meeting
80–100	Online	Course that content is delivered online, has no face-to-face meetings

Table 2: The potential benefits and pitfalls of hybrid meetings (Ellis et al., 2022)

Benefits	Pitfalls
Cheaper	More challenging
More sustain	Easy to exclude virtual attendees
Easier collaboration	Loss of non-verbal communication
Robust to change of circumstances	Require good equipment and connection
Flexible	May take longer
	Increase risk of distractions

Web-based materials can be developed to provide resources for asynchronous training. Web-based material learning can improve students' activities in physics classrooms and their learning outcomes and understanding (Sarah et al., 2022). In addition to teacher professional development, web-based learning, both online and blended, is a significant advancement in enhancing teachers' competencies by leveraging technology through computers and Internet networks (Wuryaningsih et al., 2019).

Arduino as Science Tools

Arduino offers a widely recognized open-source platform encompassing both hardware and software components, which holds substantial promise for science education. This platform is characterized by its affordability, extensive compatibility with diverse sensors and transducers, user-friendly nature, and open-source ethos, rendering it a valuable tool for fostering active and collaborative learning environments (Organtini, 2018). Several Arduino microcontroller boards in Indonesia have gained popularity, including Arduino Nano, UNO, and Atmega. Although these boards share a standard coding system, they differ in their form factor, memory capacity, port quantity, and processing speed. The Arduino UNO board is particularly well-suited for conducting laboratory experiments (Çoban and Çoban, 2020).

The versatility of the Arduino is further exemplified by its compatibility with an extensive array of sensors, including temperature, sound, humidity, pressure, light, and magnetic sensors. This diverse sensor compatibility empowers educators to conduct a wide range of physical investigations, including calorimetry, sound wave analysis, thermodynamics, and electromagnetic studies. Physics instructors have also recognized several advantages of employing Arduino boards for laboratory experiments. Among these are the substantial cost savings that schools can realize, as do-it-yourself (DIY) experimental equipment tends to be significantly more economical than commercially available alternatives. Moreover, students reported heightened engagement and enjoyment in their learning experiences when exposed to Arduino-based STEM topics (Galeriu, 2014).

In addition to these advantages, using Arduino equipment as a science experiment tool has challenges. The challenge in using Arduino as a science experiment tool is the ability to design an experiment. The skills for designing experiments using this equipment can be developed over time, drawing upon the experience gained from the simplest ones (Organtini, 2018). Another study in biomedical science using Arduino equipment in their students' activities, such as collecting data, found significant challenges in incorporating creative coding into curricula, and most students were not confident and found creative coding challenging (Gough et al., 2023).

METHOD

This case study compares the implementation of hybrid training for in-service science teachers in secondary schools in

Indonesia. Forty-one teachers from provinces across Indonesia participated in the study, as shown in Table 3. There were 22 participants from Senior High School, with 11 teachers attending the workshop face-to-face, and the remaining 11 teachers participating online. The study included 16 teachers from a Junior High School, with seven teachers participating in face-to-face sessions and nine teachers participating online from a primary school. Two teachers engaged in face-to-face instruction, while the other two used an online approach.

The training process used can be divided into three steps, namely preparation, implementation, and evaluation, as depicted in Figure 1.

The hybrid model consisted of 3 days of face-to-face and synchronous instruction and 3 weeks of fully asynchronous online training. Before the commencement of the training, all participants actively joined the Google Classroom platform. All materials were included in the Google Classroom space. Before the synchronous session for online participants and the classroom session for face-to-face participants, all participants had the opportunity to engage in independent learning through the materials available on the course website, which were also incorporated into the Google Classroom platform. Before the initial session, all participants were provided with an Arduino kit as the primary instrument for all training activities.

During the meeting sessions, the instructor provided the participants with instructional materials and helped address any questions raised by the participants. The instructor provided instructions on using the Arduino equipment to the participants, employing face-to-face interaction for the former and Zoom video conferencing for the online participants. In addition, the instructor supplemented the learning experience by providing additional video instructions for participants to access, as needed. Participants who were physically present for training received direct support from teaching assistants during the activity. In contrast, online participants relied on communication with each other and their instructor via Zoom or WhatsApp messaging platforms. The disparity in the treatment of participants involved in face-to-face interactions versus those involved in online interactions is shown in Table 4.

Table 3: Participants

Number of participants	Face to face	Online
Senior high school	11	11
Junior high school	7	9
Elementary school	1	2
Total participants	19	22

Table 4: Disparity of face-to-face and online mode training

Participants	Direct instruction platform	Assistance	Asynchronous session	Period to complete the task
Face to face	None (directly in person)	During class meeting	Google Classroom	3 weeks
Online	Zoom	During Zoom sessions, WhatsApp, and forum online	Google Classroom	3 weeks

The structure of training materials can be seen at Table 5.

In the first session, participants received material on how learning could prepare them to face future challenges. They have also been introduced to various technologies that can be integrated into science education, including Arduino microcontrollers and sensors. All the teachers were allowed to engage in self-directed learning after the session. Specifically, they were instructed to use Arduino, a web-based platform that offers open-source manufacturing and coding instructions. In the first session, Arduino materials consisted of exploring Arduino principles, introducing various electronic components, analyzing electronic circuits, demonstrating Arduino installation, and an illustrative project of light-emitting diode (LED) blinking. In the first session, the participants were tasked with developing an LED project that emulated a traffic-light simulation through coding modifications.

In the second session, the participants were introduced to the STEM learning framework and how to design learning activities based on this framework. Two key approaches were emphasized: Project-based STEM learning and the 5E model. The participants were assigned to design a learning activity based on the chosen framework. In the context of Arduino, teachers were introduced to the buzzers and ultrasonic sensors, followed by a practical exercise involving the creation of a distance sensor using Arduino.

In the last session, the participants received materials on science inquiry and computational thinking skills in the context of pedagogy. In the context of Arduino, participants were introduced to humidity sensors and servomotors. In the final session, participants were tasked with developing an independent project utilizing the newfound knowledge and

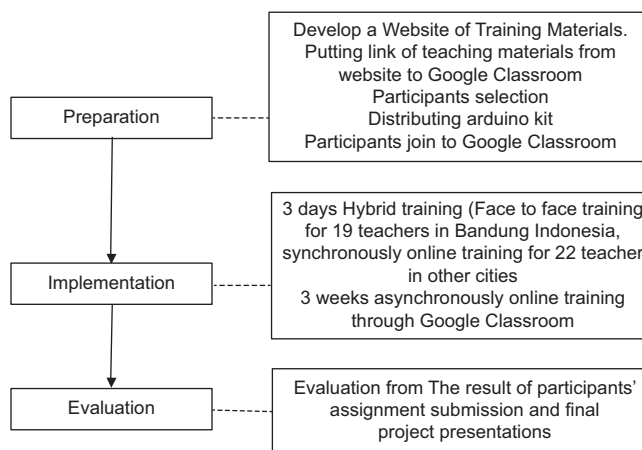


Figure 1: Activity design

Table 5: Structure of training materials

Session	Materials	
	Pedagogy context	Arduino context
First	Future learning paradigm Future Technology and its impact on education	Introduction to Arduino and electrical circuits LED basic
Second	STEM learning framework Designing STEM lesson plan	Buzzer Distance sensor
Third	Science Inquiry skills Computational thinking skills	Soil moisture sensor Motor

STEM: Science, technology, engineering, and mathematics, LED: Light-emitting diode

competencies they had acquired concerning Arduino use. In this project, the instructor guided that on the website, an illustrative demonstration of the construction of a “blind stick” was shown. However, the participants were encouraged to exhibit creativity by creating other project ideas.

At the end of each session, participants were given assignments that had to be submitted to Google Classroom, both in pedagogy and Arduino contexts. Based on the completion task submitted by the participants, a comparative analysis was conducted to determine the proportion of participants who engaged in face-to-face interactions versus those who engaged in online interactions. For each task session, the proportion was calculated as the number of participants who completed the task divided by the total number of participants in each mode. This proportion calculation is as follows:

$$\text{Proportion } (\hat{p}) = \frac{\text{Participants who complete the task}}{\text{Total participants}} \quad (1)$$

Based on the proportion for each session, the data were analyzed for significant differences using the proportion of different significant values, z test, as follows:

$$z = \frac{(\hat{p}_1 - \hat{p}_2)}{\sqrt{\hat{p}(1-\hat{p})\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}} \quad (2)$$

Where: n_1 is the number of face-to-face participants, n_2 is the number of online participants, \hat{p}_1 is the proportion of face-to-face participants who completed the task, \hat{p}_2 is the proportion

of online participants who completed the task. Finally, the pooled proportion p is used with assumption that the two population proportions are equal. Pooled proportion is used to determine the error standard while examining z value. The pooled proportion is calculated as:

$$p = \frac{(\hat{p}_1 \cdot n_1 + \hat{p}_2 \cdot n_2)}{n_1 + n_2} \quad (3)$$

Finally, from the z -test result, we conclude by using a significance level significant value (α) = 0.05. If the absolute

z -value exceeds 1.96 or if the p -value is less than 0.05, the result is considered statistically significant and concludes that there is a meaningful difference between the two proportions being compared (Moore et al., 2014). To strengthen the conclusions, we also conducted several questionnaires regarding the difficulties or challenges teachers faced when participating in this training.

RESULTS AND DISCUSSION

As a result of the preparation phase, all instructional materials outlined in Table 5 were uploaded to Google Classroom and a dedicated website. All participants were required to join Google Classroom, complete the necessary administrative procedures, access information regarding Zoom meeting sessions, unbox the distributed Arduino kits, and review the preliminary materials as prior knowledge.

Subsequently, online participants joined the Zoom meeting sessions to receive direct instruction from experts, while face-to-face participants attended face-to-face classes with experts. Both online and face-to-face participants had the opportunity to engage directly with experts through discussion and Q&A sessions. During the pedagogy session, participants actively engaged in lectures delivered by the experts, as evidenced by the high number of questions posed and dynamic discussions. The pedagogy session lasted approximately 2 h, covering two topics, followed by a 2-h break.

The Zoom session was then resumed using the Arduino instructional segment. During this session, the participants were required to open their Arduino kits and follow the expert’s guidance on using Arduino. At the installation stage, some online participants encountered difficulties in installing the Arduino IDE because of non-genuine operating systems, which made it challenging for the expert team to provide remote assistance. In addition, during the basic LED circuit assembly, some participants struggled with connecting the electronic components on the breadboard. In the face-to-face class, participants received support not only from the expert team but also from more experienced peers, particularly teachers with a background in physics education. However, online participants, who lacked prior experience in assembling electronic components, required one-on-one facilitation. Consequently, in the first session, several participants were unable to successfully complete the basic LED circuit task.

In subsequent sessions, the complexity of the Arduino projects progressively increased. In the final session, participants were required to develop an Arduino project related to the science subjects they had taught, which would later be assigned to their students. Number of participants completed the task are presented in Table 6.

The task completion rates presented in Table 6 illustrate the performance differences between face-to-face and online participants across each session. In the initial sessions, both groups demonstrated relatively high completion rates, with

face-to-face participants consistently achieving 0.89 or 89% completion, and online participants showing slightly lower completion rates at 0.82 or 82%. However, as the project complexity increased in subsequent sessions, a noticeable gap emerged between the two groups. In the second session, the completion rate for face-to-face participants decreased slightly to 0.79, while the online participants' completion rate declined more substantially to 0.64. This trend became more pronounced in the final session, which required participants to design an Arduino project aligned with their teaching subjects. In this session, the face-to-face group maintained a completion rate of 0.79, whereas the online group experienced a significant drop to 0.41. These findings suggest that as the tasks became more complex and required higher levels of problem-solving and creativity, online participants faced greater challenges in completing the assignments compared to their face-to-face counterparts. Based on the proportion, Table 7 shows calculation z-test proportion.

In the first session, participants learned to write a program based on the examples provided and then modified the program to complete the traffic light simulation challenge.

Based on the z-test proportion, there was no significant difference between face-to-face and online participants.

In the second session, the project difficulty level was higher than that in the first session. The participants learned about the buzzer and ultrasonic HCSR04 sensor by assembling all components into physical circuits (breadboards) based on wiring diagrams and modifying code. As a result of completing the second project session, 79% ($\hat{p}_1 = 0.79$) of face-to-face participants and 64% ($\hat{p}_2 = 0.64$) of online participants were

able to complete the project. There was also no significant difference based on the z-test of the proportions in the second session. Meanwhile, for the third session, the participants were challenged to create a project that was different from the projects presented in the training. The completion results of this project for face-to-face participants were 79% ($\hat{p}_1 = 0.79$), whereas for online participants, only 41% ($\hat{p}_2 = 0.41$). Most secondary school teachers in face-to-face training completed the assignments. They made various projects using the Arduino UNO, such as a flood alarm system, intelligent watering system, and sensor detection for social distancing. They can write their own code in an Arduino software program, modify it, create new code, and write code based on what is required. However, online participants struggled to meet the challenges of completing more complex projects.

Based on the z-proportion test, there was a significant difference between face-to-face and online participants' achievements. As an illustration of the project completion process for face-to-face participants, it was carried out in groups in the classroom so that the participants could work together. Even though the participants worked independently, the collaborative process enabled other participants to complete the project successfully. Meanwhile, collaborative activities were difficult for online participants because of time differences across project completions. Online participants also experienced difficulties, especially when translating the wiring diagram to the electrical circuit (breadboard), resolving of error code, modification of the project, mitigation of connectivity issues between the Arduino equipment and computers, and time constraints on project completion. Face-to-face participants also experienced this difficulty, but this challenge could be resolved through collaboration and direct assistance.

Several STEM project topics developed by the participants during this training were novel, and they independently explored these topics by leveraging their existing knowledge. However, most online participants who completed the final assignment merely duplicated the example project provided, which was based on the blind stick theme. A detailed overview of STEM project themes is shown in Figure 2.

Based on the results shown in Figure 2, online participants tended to duplicate the provided example projects without attempting to introduce new elements, unless explicitly instructed. To gain a deeper understanding of this phenomenon, researchers conducted interviews with representatives of online participants. The first participant was a science teacher at a secondary school with a physics education background. He stated:

“Arduino is something new to me; this is my first time using it. I was able to complete the assignments by following the provided guidelines. However, I do not fully understand the meaning of each line of code in the program. I think I need to study it further. But I am confident that my students will be more adept at

Table 6: Completion rate (proportion)

Session	Practical of using Arduino	Face-to-face complete task			Online complete task		
		Yes	No	\hat{p}_1	Yes	No	\hat{p}_2
1	Arduino Installation	17	2	0.89	18	4	0.82
	Blink LED	17	2	0.89	18	4	0.82
2	Buzzer and Ultrasonic Sensor	15	4	0.79	14	8	0.64
3	Application to Solve Problem	15	4	0.79	9	13	0.41
	Total participants	19			22		

Table 7: Calculation z test proportion

Session	Practical of using Arduino	\hat{p}_1	\hat{p}_2	z	p	result
1	Arduino Installation	0.89	0.82	0.69	0.49	No significant
	Blink LED	0.89	0.82	0.69	0.49	No significant
2	Buzzer and ultrasonic sensor	0.79	0.64	1.07	0.28	No significant
3	Application to solve problem	0.79	0.41	2.47	0.01	Significant

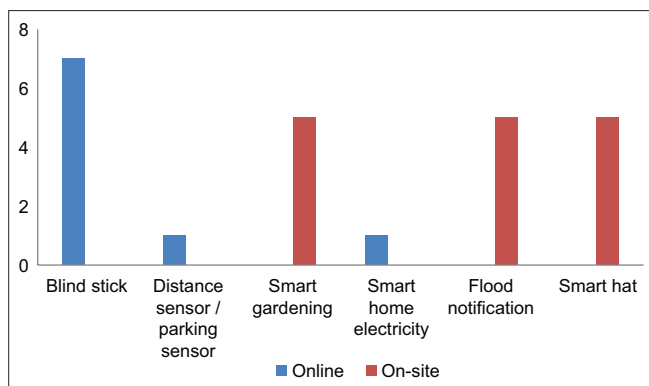


Figure 2: Final science, technology, engineering, and mathematics project

understanding technology, so I can also learn together with them in the future.”

The second participant, a high school biology teacher who also developed a blind stick as their final project, expressed the following:

“I actually found learning Arduino quite challenging, especially when following the step-by-step guide but still encountering issues. Fortunately, I had an ICT teacher here who was willing to help me complete the project. When implementing this in the classroom, I will likely collaborate with that teacher as well.”

One interesting finding from this study is the completion task results of the elementary school teachers. One elementary school teacher attended face-to-face training but failed to engage and participate from the start. He struggled to complete the assignment even though he received assistance in the classroom. He seemed to understand the writing code but could not modify or construct it. He commented that writing code in the Arduino software was too complicated and that his students would struggle, so his motivation to complete the training was not as strong as that of secondary school teachers. However, two elementary school teachers attended online training to complete all projects and sessions. They both stated that this training and the use of Arduino in the classroom are engaging. This perspective, in line with the results of the course questionnaire, indicated that most educators (85%) expressed a shared perspective on the viability of the Arduino tools as instruments for enriching science education.

Based on observations during the implementation and interviews with both online and face-to-face participants, the main challenges encountered when using Arduino were related to programming and wiring diagrams. For teachers without a programming background, even minor errors such as missing a semicolon at the end of a code statement often lead to frustration. Translating schematic diagrams into actual circuits also poses a significant challenge, as devices frequently fail to function because of loose connections or incorrect wire placement. Therefore, it is reasonable to suggest that, before conducting Arduino training, participants should first be provided with fundamental knowledge of circuit design.

Despite these challenges, integrating Arduino into science classes has provided science teachers with a new perspective. They recognized the potential to design science lessons that incorporate technology and integrate it with other subjects, such as mathematics. In addition, teachers expressed confidence that incorporating technology, particularly Arduino, into science education could help students develop their engineering design process skills. This perspective is in line with other research stating that using Arduino in the classroom promotes students’ inquiry skills and develops their engineering practices (Pino et al., 2018).

Hands-on Arduino training, conducted in a hybrid mode through both face-to-face and online sessions using Zoom and Google Classroom, had a positive impact on teachers’ skills, particularly in integrating Arduino into science instruction for relatively simple projects with moderate complexity. This is evident from the task completion rate, which exceeded 60%. However, online participants require additional support for more complex projects. Those who struggled or had difficulty following the training from the first session benefited from one-on-one facilitation.

Nevertheless, based on the task completion rates and participant responses, hybrid training on Arduino integration in science education was valuable and had a positive impact. It helped teachers design science lessons that aligned with contemporary technological advancements and better prepare students for future challenges.

CONCLUSION

Hybrid science teacher training in Web-Arduino-based science projects with face-to-face and online participants can be successful when materials are designed and planned instructions are in place. However, the results were not significantly different for face-to-face and online participants in Arduino-based science projects of low or medium complexity. This outcome was demonstrated by the results of task completion from face-to-face and online participants in the first and second sessions of this study. However, science teachers’ professional development sessions using Arduino-based resources for science projects requiring greater creativity or complexity indicate significant differences in outcomes between face-to-face and online participants. This outcome may indicate that hybrid training processes or approaches require further development. Several challenges of hybrid science teacher training on Web-Arduino-based equipment for science projects need to include the effective translation of wiring diagrams to physical circuits (breadboards), resolution of coding errors, mitigation of connectivity issues between the Arduino equipment and computers, and the constraint of time on project completions. To improve future hybrid training programs, it is recommended to offer pre-training sessions on basic circuitry to strengthen the participants’ fundamental skills, especially for online learners. In addition, providing peer support channels such as mentoring groups, interactive

forums, or real-time consultation opportunities may help participants overcome difficulties more effectively and enhance task completion rates in online settings.

ACKNOWLEDGMENT

This research was supported by the SEAMEO-Australia Education Links Award. The authors sincerely appreciate the funding and support provided for the successful completion of this study.

ETHICAL COMPLIANCE

All participants volunteered to take part in the research and did not have an objection of publication their responses. Name is a pseudonym.

CONFLICT OF INTEREST

There is no conflict of interest in this paper.

REFERENCES

- Alezezi, M., Wardat, S., & Akour, M. (2023). The need of integrating digital education in higher education: Challenges and opportunities. *Sustainability*, 15(6), 4782.
- Brown, L., & White, S. (2019). Internet-based tools in education: A review of current practices. *Educational Technology*, 38(4), 567-584.
- Çoban, A., & Çoban, N. (2020). Using Arduino in physics experiments: Determining the speed of sound in air. *Physics Education*, 55(4), 043005.
- Dat, N.D., Van Bien, N., Khuyen, N.T.T., Ha, N.T.V., An, H.T.T., & Anh, N.T.P. (2024). Arduino-based experiments: Leveraging engineering design and scientific inquiry in STEM lessons. *International Journal of STEM Education for Sustainability*, 4(1), 38-53.
- Deng, L., & Tavares, N.J. (2015). Exploring university students' use of technologies beyond the formal learning context: A tale of two online platforms. *Australasian Journal of Educational Technology*, 31(3), 313-327.
- Ellis, R., Goodacre, T., Mortensen, N., Oeppen, R.S., & Brennan, P.A. (2022). Application of human factors at hybrid meetings: Facilitating productivity and inclusivity. *British Journal of Oral and Maxillofacial Surgery*, 60(6), 740-745.
- Galeriu, C., Edwards, S., & Esper, G. (2014). An Arduino investigation of simple harmonic motion. *Physics Teacher*, 52(3), 157-159.
- Galeriu, I. (2014). Enhancing student engagement in physics through Arduino-based STEM topics. *Journal of Science Education*, 29(2), 123-140.
- Garrison, D.R., & Kanuka, H. (2004). Blended learning: Uncovering its transformative potential in higher education. *The Internet and Higher Education*, 7(2), 95-105.
- Gough, P., Bown, O., Campbell, C.R., Poronnik, P., & Ross, P.M. (2023). Student responses to creative coding in biomedical science education. *Biochemistry and Molecular Biology Education*, 51(1), 44-56.
- Haleem, A., Javaid, M., Qadri, M.A., & Suman, R. (2022). Understanding the role of digital technologies in education: A review. *Sustainable Operations and Computers*, 3, 275-285.
- Honey, M., & Kanter, D.E. (2013). *Design, Make, Play: Growing the Next Generation of STEM Innovators*. England: Routledge.
- Johnson, A., & Smith, P. (2020). Enhancing science and technology education for the 21st century. *Journal of Educational Research*, 45(2), 189-204.
- Johnson, M. (2021). Preparing students for the 21st century: The role of educators. *Journal of Educational Strategies*, 25(2), 123-140.
- Kotseva, I., Gaydarova, M., Angelov, K., & Hoxha, F. (2019, February). Physics experiments and demonstrations based on Arduino. *AIP Conference Proceedings*, 2075(1), 180021.
- Mason, J., Shaw, G., & Zhang, D. (2019). Shifting pedagogies and digital technologies shaping futures in education. In: *Shaping Future Schools with Digital Technology: An International Handbook*. Germany: Springer Nature, pp. 201-223.
- Moore, D.S., McCabe, G.P., & Craig, B.A. (2014). Introduction to the Practice of Statistics. 8th ed. United States: W.H. Freeman.
- National Research Council (U.S.). (1996). *National Science Education Standards : Observe, Interact, Change, Learn*. United States: National Academy Press.
- National Research Council. (2012). *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. United States: National Academies Press.
- Organtini, G. (2018). Arduino as a tool for physics experiments. *Journal of Physics Conference Series*, 1076(1), 012026.
- Pino, H., Pastor, V., Grimalt-Álvaro, C., & López, V. (2018). Measuring CO₂ with an Arduino: Creating a low-cost, pocket-sized device with flexible applications that yields benefits for students and schools. *Journal of Chemical Education*, 96, 377-381.
- Reaves, J. (2019). 21st-century skills and the fourth industrial revolution: A critical future role for online education. *International Journal on Innovations in Online Education*, 3(1), 1-17.
- Sarah, L., Ananto, Y., Octanary, D., & Nussifera, L. (2022). The design and Implementation e-scaffolding enhance learning (ESEL) using web-based simulation on moment of Inertia. *Techno Journal Penelitian*, 11(1), 28-37.
- Sarah, L.L. (2021). Automatic trash bin Arduino project (ATAP): Enhancing computational thinking skills through STEM learning. *SEAQIS Journal of Science Education*, 1(1), 27-35.
- Sarah, L.L., Ananto, Y., Octanary, D., & Nussifera, L. (2022). The implementation of web based e-scaffolding enhance learning (ESEL) on centre of mass concept understanding. *Journal Inovasi Pendidikan IPA*, 8(1), 37-46.
- Shaw, G. (2011). Education for rural transformation through principals' professional development in Indonesia. In: *Dujiangyan International Forum: Conference*. France: Unesco, pp. 145-157.
- Shaw, G., & Northedge, A. (2018). Learning and teaching in the online era. In: *Successful University Teaching in Times of Diversity*. United Kingdom: Macmillan Education, pp. 83-109.
- Smith, P. (2019). Enhancing science education through pedagogical innovation. *Journal of Science Education*, 28(3), 210-225.
- Smith, P., & Johnson, A. (2020). Enhancing science education through technology. *Journal of Educational Technology*, 35(2), 123-140.
- Smith, R., Johnson, A., & Brown, L. (2022). Facilitating meaningful learning in the digital age. *Educational Technology Research*, 45(1), 34-49.
- Sundeen, T.H., & Sundeen, D.M. (2013). Instructional technology for rural schools: Access and acquisition. *Rural Special Education Quarterly*, 32(2), 8-14.
- Wuryaningsih, W., Susilastuti, D.H., Darwin, M., & Pierewan, A.C. (2019). Effects of web-based learning and F2F learning on teachers achievement in teacher training program in Indonesia. *International Journal of Emerging Technologies in Learning*, 14(21), 123-147.