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Integrating Microcontroller Programming and 3D Design for Community-based Experiential Learning

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Abstract

This study presents a community based workshop designed to enhance digital literacy through hands-on learning that combines microcontroller programming and three-dimensional (3D) design. The activity adopted a Do It Yourself (DIY) approach to bridge theoretical understanding and practical skills. Participants, consisting of students and young learners, developed a functional digital clock using an Arduino based microcontroller and designed its custom 3D printed enclosure. A mixed-method evaluation was conducted to assess learning outcomes. Quantitative results from a post activity questionnaire showed a high satisfaction level, with an overall mean score of 3.41, categorized as very high across five learning aspects which are motivation, comprehension, facilitation, relevance, and reflective impact. Qualitative feedback supported these findings, indicating that participants gained confidence, curiosity, and a deeper understanding through direct experimentation and collaborative mentoring. The results confirm that short term, project based workshops can effectively improve digital competence and creative confidence in community settings. Integrating accessible hardware and affordable fabrication tools provides a scalable model for STEM oriented education. The initiative demonstrates how experiential learning can promote innovation, problem solving, and technological empowerment, offering a sustainable framework for future programs in digital literacy and maker based education.

1. INTRODUCTION

Digital technology continues to reshape how people learn, work, and create. The rapid growth of automation, artificial intelligence, and smart systems has transformed many aspects of daily life. In the context of the Fourth Industrial Revolution (Industry 4.0), understanding the fundamentals of electronics, microcontrollers, and three-dimensional (3D) design is no longer optional, it has become a key competency. These skills are crucial

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not only for engineering students but also for wider communities that must adapt to continuous technological change.

Despite this growing importance, many educational institutions still deliver technology courses in a largely theoretical manner (Salinas-Navarro et al., 2023). Students often study programming or circuit design through lectures and simulations, but rarely engage in direct experimentation. Without practical exposure, learners struggle to connect abstract concepts with physical outcomes (Hajshirmohammadi et al., 2020; Tembrevilla et al., 2024). This lack of experiential learning often weakens motivation and limits the development of digital literacy required in modern industry.

To address this gap, a hands-on learning initiative was introduced to enhance participants' understanding of digital systems through project based practice. The workshop focused on building a functional digital clock using a microcontroller, accompanied by the design and fabrication of a 3D printed enclosure. This activity combined three essential domains: electronics, programming, and product design, into one continuous learning experience that encouraged participants to apply theory to a real, working prototype.

The learning process was guided by the Do It Yourself (DIY) approach (Gibbons & Snake-Beings, 2018), which promotes independence, curiosity, and creativity. DIY learning has been recognized as an effective pedagogical strategy that empowers learners to take ownership of their projects and to learn through exploration and iteration (Khoo & Kang, 2022; Pearson & Dubé, 2025). In this workshop, participants were introduced to each stage of development, from wiring components and writing microcontroller code to designing a 3D casing using computer aided design tools. Each step built upon the previous one, helping participants see how electronic and mechanical systems interact in a complete product.

Beyond technical mastery, the workshop also sought to cultivate confidence and a deeper appreciation of how digital technologies connect with real world applications. Participants were encouraged to experiment, make mistakes, and refine their work, reflecting the authentic process of engineering design (Kolodner et al., 2003). Research has shown that iterative, hands-on learning significantly improves retention, engagement, and creative problem solving skills in STEM education (Sukackė et al., 2022; Yüksel, 2025)

The objective of this community engagement program was therefore twofold: to strengthen participants conceptual understanding of digital electronics and microcontrollers, and to introduce practical 3D design and fabrication as complementary skills. By merging these learning components, the program aimed to foster interdisciplinary competencies aligned with Industry 4.0 requirements (Garcia-Moran et al., 2021; Munir et al., 2024). In addition, the initiative encouraged participants to pursue independent, open ended projects after the workshop, promoting a sustainable culture of creativity, innovation, and lifelong learning within their communities.

In this context, the objectives of this community engagement program were twofold: (i) to strengthen participants conceptual understanding of digital electronics and microcontrollers, and (ii) to introduce contemporary design and fabrication techniques through interdisciplinary practice. By integrating microcontroller based projects with 3D modeling and printing, the program sought to develop transferable competencies aligned with Industry 4.0 skill demands. Furthermore, it encouraged participants to pursue independent, open ended projects, fostering a sustainable culture of creativity, innovation, and lifelong learning.

2. METHOD AND IMPLEMENTATION

2.1. Activity Design and Implementation

The community engagement activity was conducted as an intensive workshop that combined theoretical instruction, hands-on experimentation, and reflective evaluation. The approach followed the principles of Do It Yourself (DIY) engineering, in which participants actively construct a tangible product while internalizing key theoretical concepts. The core project involved designing and assembling a microcontroller based digital clock, followed by creating a custom 3D printed enclosure using accessible computer aided design (CAD) tools.

The workshop is held in 2 days with six participants, and took place at the Robotics and Intelligent Computing Laboratory, School of Bioscience, Technology, and Innovation, Universitas Katolik Indonesia Atma Jaya. The laboratory was equipped with microcontroller kits, soldering tools, and a 3D printer to support prototyping activities. Participants, comprising students and young learners from local institutions, were grouped into small teams to promote peer learning and collaborative problem solving.

The workshop was structured into three main stages, as illustrated in Figure 1, covering the phases of design, assembly, and evaluation. Facilitators guided participants through each stage, ensuring that every team completed a functional prototype by the end of the session. Throughout the activities, participants were encouraged to identify and troubleshoot issues independently, fostering self directed exploration, persistence, and critical thinking.

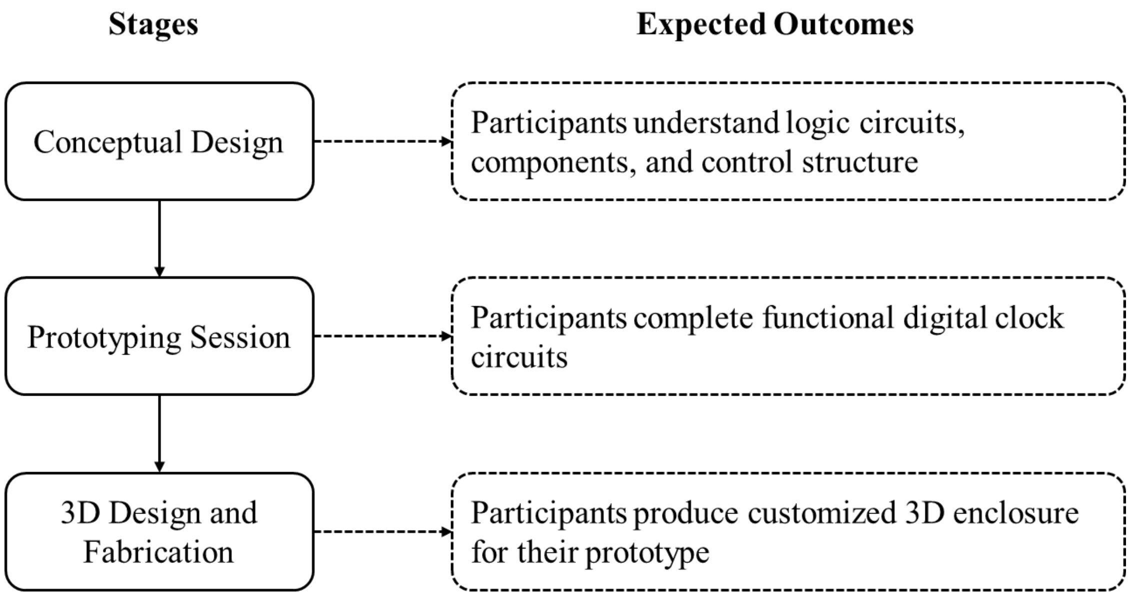

Figure 1.
Workshop Activity Design Diagram

The workshop session began with electrical wiring based on the schematic shown in Figure 2, where each participant assembled their own circuit to reinforce understanding of component functions and connections. Following this, participants uploaded and modified microcontroller code to display real time digital clock data on a dot matrix LED module.

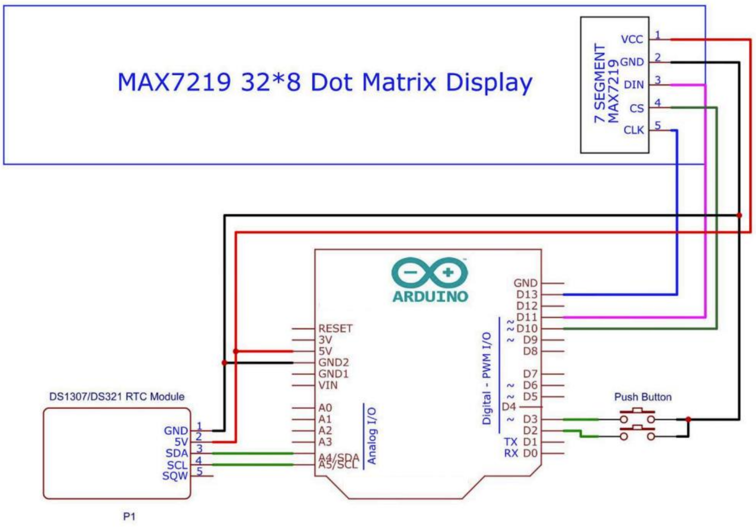

Figure 2.
The Schematic of Electrical Wiring

After completing the programming stage, the workshop moved to 3D design. Participants used computer-aided design software to model the enclosure of their digital clock, which was then fabricated using a fused deposition modeling 3D printer. The resulting designs showcased both creativity and precision, as shown in Figure 3.

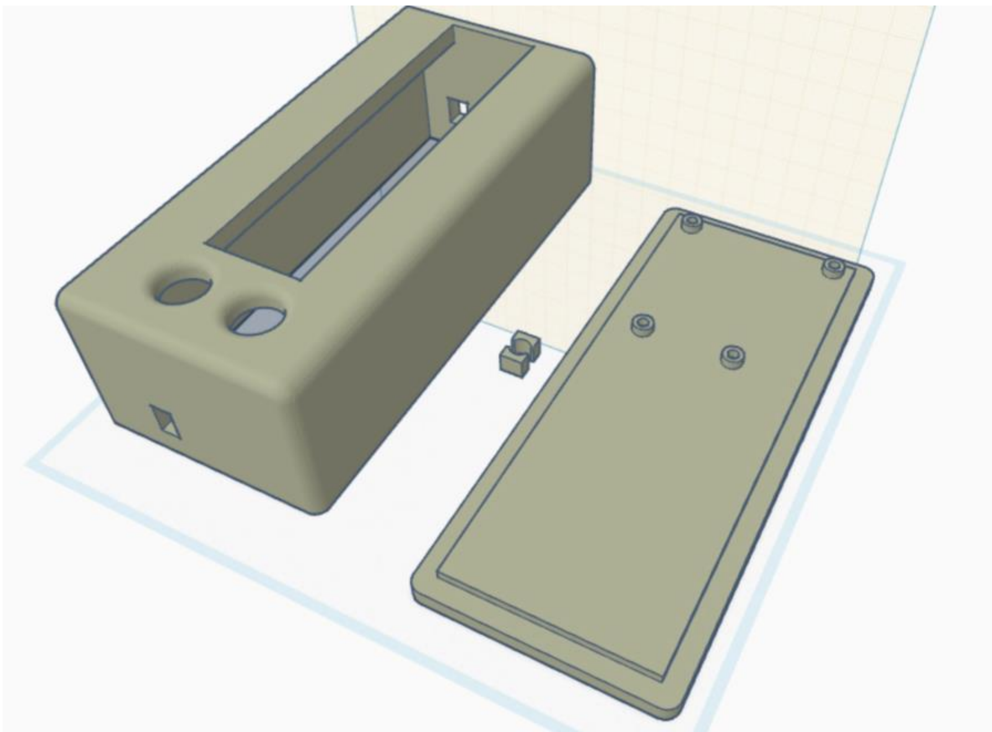

Figure 3.
3D Enclosure Design

This full sequence allowed participants to experience the end to end process of digital product creation, from electronic assembly to design fabrication. Such integration encouraged interdisciplinary learning, strengthened spatial reasoning, and promoted hands-on problem solving. The activity is shown in Figure 4, capturing the collaborative and experimental nature of the sessions.

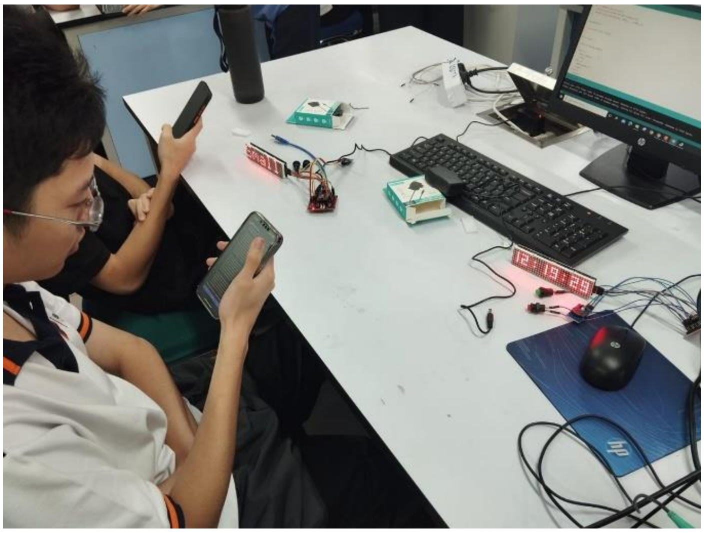

Figure 4.
Workshop Activity

2.2. Evaluation Design

To measure learning outcomes, a post workshop questionnaire consisting of 15 items was administered. Each item was rated on a four point Likert scale (Chang, 1994), ranging from 1 (Strongly Disagree) to 4 (Strongly Agree). The instrument evaluated five major learning aspects aligned with the workshop objectives, as summarized in Table 1.

Table 1.
The mapping of learning aspects and questionnaire components

Aspect	Description	Related Items	Focus
Motivation and Engagement	Measures enthusiasm, willingness, and initiative to join the activity	1–3	Interest, curiosity, and voluntary participation
Clarity and Understanding of Material	Evaluates understanding of theoretical and practical content	4–6	Comprehension of electronic principles and coding logic
Facilitator and Delivery Quality	Assesses clarity, responsiveness, and instructional effectiveness	7–9	Teaching clarity and quality of assistance
Relevance and Applicability	Identifies perceived usefulness of the workshop for future projects	10–12	Connection to real world or academic relevance

Each aspect represents a key construct in engineering education and community empowerment, ensuring that the evaluation captured both pedagogical and social dimensions of learning.

2.3. Data Collection and Analysis

Participant responses were tabulated and analyzed quantitatively by calculating the mean score of each item and the aggregated mean per aspect. To aid interpretation, each mean score (x) was categorized using the scale shown in Eq. (1). This classification provided a descriptive indicator of participants' satisfaction and perceived learning achievement.

$$\begin{cases} Very\ High, & 3.25 < x \leq 4.00 \\ High, & 2.50 < x \leq 3.25 \\ Moderate, & 1.75 < x \leq 2.50 \\ Low, & 1.00 < x \leq 1.75 \end{cases} \qquad \text{..} \quad (1)$$

In addition to quantitative data, an open ended section titled "Impression and Message" allowed participants to share qualitative feedback. This included reflections on their experiences, challenges, and perceived benefits. The responses were analyzed thematically and grouped into three recurring themes: (i) enjoyable learning experience, (ii) practical skill acquisition, and (iii) interest in continued exploration. The combination of quantitative and qualitative data enabled triangulation and enhanced the validity of findings. This multidimensional analysis ensured that workshop outcomes were measurable, interpretable, and replicable for future community based STEM literacy programs. The next section presents participant response analysis and discusses pedagogical implications derived from these results.

2.4. Ethical Considerations

All participants were informed about the voluntary nature of their participation and the confidentiality of their data. No identifying information was collected, and all responses were used exclusively for educational development and dissemination in community engagement contexts

3. RESULT AND DISCUSSION

The post workshop questionnaire results reflect participants' perceptions of the learning experience. The average scores across all 15 statements ranged from 3.00 to 4.00, indicating consistently positive responses. Based on the interpretive scale in Eq. (1), eleven of the fifteen indicators reached the very high category. This confirms that most participants expressed strong agreement with statements related to satisfaction, clarity, and engagement. Such uniformly high ratings suggest that the workshop was effective not only in building technical understanding but also in fostering an enjoyable and motivating learning atmosphere. The descriptive summary of scores is presented in Table 2.

Table 2.
Descriptive Summary of Questionnaire Results

No	Mean Score	Interpretation
1	3.5	Very High
2	3.17	High
3	3	High
4	3.17	High
5	3.17	High
6	3.33	Very High
7	3.33	Very High
8	4	Very High
9	3	High
10	3.67	Very High
11	3.67	Very High
12	3.17	High
13	3.5	Very High
14	3.67	Very High
15	3.67	Very High
Overall Mean	3.41	Very High

To provide further insight, the 15 items were grouped into five learning aspects as defined earlier in Table 1. The mean scores per aspect are shown in Table 3.

Table 3.
Descriptive Summary of Questionnaire Results

Learning Aspect	Associated Items	Mean Score	Interpretation
Motivation and Engagement	1–3	3.22	High
Clarity and Understanding	4–6	3.22	High
Facilitator and Delivery	7–9	3.44	Very High
Relevance and Applicability	10–12	3.50	Very High

The analysis shows that Impact and Reflection received the highest rating. Participants not only enjoyed the activity but also reported meaningful learning outcomes and motivation for further exploration. Although Motivation and Engagement and Clarity and Understanding scored slightly lower, both remained within the high category. This indicates that participants entered the workshop with interest but might benefit from extended duration or additional scaffolding to strengthen conceptual mastery.

Qualitative feedback supported these findings and offered richer context to the numerical data. Many participants described the activity as “exciting and fun,” highlighting emotional engagement and enthusiasm during hands-on tasks. Others commented, “I now understand basic electronics,” reflecting cognitive gains achieved through direct experimentation. Another participant summarized their impression simply as “the workshop was cool,” capturing the overall positive atmosphere. Although brief, these remarks collectively illustrate that the workshop successfully integrated enjoyment, understanding, and relevance, key components of meaningful learning.

The overall mean score of 3.41 placed the activity within the very high satisfaction category. Participants showed enthusiasm for learning and recognized the value of combining microcontroller programming with 3D design as complementary skills. High scores on facilitator performance (items 7–9) emphasized the importance of clear mentoring and timely feedback during complex technical tasks. However, moderate variation among comprehension items (4–6) suggests that some learners required more step by step guidance or longer sessions to internalize circuit logic and programming syntax. This observation supports extending future implementations into multi session modules or incorporating pre workshop learning materials.

Beyond the survey data, the workshop’s practical stages further demonstrated participants’ learning progress.

Combining DIY microcontroller projects with 3D fabrication effectively connected theoretical knowledge to tangible results. The increased curiosity and confidence observed among participants align with the broader goals of STEM literacy and community technological empowerment. The approach also demonstrates scalability, suggesting that similar workshops could be adapted for secondary education or local maker communities to encourage early engagement with digital fabrication and embedded system concepts.

The mixed method evaluation confirmed that the workshop achieved its intended objectives. Participants reported strong intrinsic motivation, improved comprehension of digital electronics, and continued interest in pursuing related projects. These findings affirm the effectiveness of community based, project driven workshops in enhancing technical literacy, creativity, and confidence among young learners.

4. CONCLUSION

The community based workshop integrating microcontroller programming and 3D design demonstrated an effective model for experiential technology education. Quantitative analysis of the post activity survey revealed a high satisfaction level, with an overall mean score of 3.41 across all five learning dimensions namely motivation, comprehension, facilitation quality, relevance, and reflective impact. Qualitative feedback supported these findings, showing that participants gained confidence, enjoyment, and meaningful cognitive benefits through hands-on creative engagement. The combination of DIY learning and collaborative mentoring created a dynamic learning environment that encouraged exploration and problem solving, even among participants with limited prior experience in electronics or design.

The results confirm that short term, project based workshops can substantially enhance digital literacy and creative confidence within local communities. The integration of accessible Arduino based hardware and affordable fabrication tools such as 3D printing provides a scalable foundation for community empowerment through engineering practice. Participants' strong engagement and positive feedback suggest that similar initiatives could serve as entry points for broader topics such as the Internet of Things (IoT), automation, and digital manufacturing in future programs.

Nevertheless, several areas for improvement were identified. While participants grasped key concepts, some required more structured guidance during programming and circuit testing. Extending the workshop duration or dividing it into multiple sessions may support deeper understanding and skill retention. Providing pre workshop materials, such as short video tutorials or simplified schematics, could improve readiness and help equalize participants' baseline knowledge. Additionally, incorporating peer mentoring or follow up online sessions may sustain learning momentum after the event.

Overall, the program successfully achieved its objectives of strengthening participants' technical literacy, creative problem solving skills, and motivation for self directed exploration. These outcomes underscore the educational value of community engagement that merges engineering education with practical innovation. Future implementations should emphasize continuity, inclusivity, and collaboration with local maker communities and educational institutions to broaden the program's reach and sustainability. By combining technical learning with participatory design and reflection, similar community based workshops can serve as catalysts for nurturing a generation of adaptable, innovative, and technologically proficient learners.

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