

A Value-Based Participatory STEM Integration Model: Improving Teacher Competence through the Hydroponic Eco Tower Project

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ABSTRACT

21st-century education demands that teachers have practical competencies in implementing STEM (Science, Technology, Engineering, and Mathematics) learning. However, teachers often face a gap between theoretical understanding and practical application, exacerbated by contextual constraints such as limited land in urban schools. This study aims to improve practical STEM competencies for teachers at Sabilurrosyad Islamic Junior High School in Malang City through a Participatory Action Research (PAR)-based intervention. The PAR method was implemented in four cycles: (1) Participatory planning to identify problems (limited land) and potential (ablution water utilization); (2) Action design in the form of implementing a Hydroponic Eco Tower; (3) Action implementation through a practical assembly workshop; and (4) Simultaneous observation and reflection. The results of the study showed high enthusiasm and active participation of teachers throughout the process, which successfully transformed their roles from passive objects to active subjects. One prototype unit of the Hydroponic Eco Tower was successfully assembled and implemented by the teachers. More importantly, the PAR process identified a crucial technical finding (the need for flannel for water distribution) that triggered authentic thinking and problem-solving. This study concluded that the PAR method anchored in contextual-religious values (the use of ablution water) was effective in transferring competencies. This model resulted in the "Values-Based Participatory STEM Integration Model" as a recommended framework for teacher professional development in similar educational institutions.

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1. INTRODUCTION

21st-century education, often touted as being in line with the Industrial Revolution 4.0 and the Independent Curriculum, demands a paradigm shift from passive learning to active and applied learning. The primary focus is no longer solely on mastering material, but on developing crucial competencies such as critical thinking, problem-solving, creativity, and collaboration. To address this challenge, the STEM (Science, Technology, Engineering, and Mathematics) approach has emerged as a key pillar of education reform.

STEM is not simply an acronym for four disciplines taught separately. The true essence of STEM lies in its integration; an interdisciplinary learning approach where academic concepts are combined with problem-solving in real-world contexts. Unfortunately, the implementation of STEM in many schools, including at the junior high school level, still faces obstacles. Teachers often understand STEM theoretically but struggle to translate it into engaging and relevant learning practices for students. Teachers' competency in designing and facilitating real-life STEM-based projects is a gap that needs to be addressed immediately.

To bridge this gap, a learning platform is needed that is hands-on, contextual, and able to fully integrate all aspects of STEM. Such a platform should not only introduce scientific concepts but also encourage teachers to experience the process of designing, testing, and improving a real product. One of the most relevant solutions, especially for urban schools with limited land, such as in Malang City, is hydroponic technology. Hydroponics provides an accessible learning medium because it can be implemented in narrow spaces while still demonstrating the interaction between science, technology, engineering, and mathematics. Through this approach, teachers can directly connect classroom theory with practical problem-solving activities that are meaningful for students. Therefore, hydroponic technology offers a strategic entry point for strengthening teacher competence in applied STEM learning.

Hydroponics, or the practice of growing plants without soil, is a perfect example of real-world STEM applications. Hydroponics projects inherently force learners to engage in:

- Science: Studying plant biology, photosynthesis, nutrient cycling, and measuring water quality parameters (pH, PPM).
- Technology: Using and understanding how tools work, such as water pumps, drip irrigation systems, and in this context, "Eco Tower" technology (vertical farming) as a solution for limited land.
- Engineering: Performing design and engineering processes. This includes assembling installations, solving problems (e.g., how to distribute water evenly), and even innovating, such as designing systems to utilize renewable resources (e.g., water for ablution).
- Mathematics: Performing precision calculations for nutrient solution concentration (AB Mix), measuring water volume, calculating seed ratios, and analyzing plant growth rates.

Therefore, the community service program at Sabilurrosyad Islamic Junior High School in Malang City was designed to directly improve teachers' STEM competencies through practical exercises. The "Hydroponic Eco Tower" was used as a case study, the idea of which was to utilize ablution water. This program provided not only theory but also hands-on experience (experiential learning). Teachers were encouraged to become engineers, scientists, and problem-solvers so they would be prepared to guide their students with the same approach.

2. RESEARCH METHODS

Research Design

This research uses a Participatory Action Research (PAR) design. Participatory Action Research (PAR) is a collaborative research approach that involves researchers and participants working together throughout the research process. This method aims to address real-world problems, create practical solutions, and drive social change, with the entire research process co-owned by all stakeholders [1], [2], [3]. PAR emphasizes the active involvement of participants, especially those from marginalized communities, in all phases of the research process [2], [3], [4]. This approach involves iterative cycles of action and reflection, enabling continuous learning and adaptation [5], [6]. PAR aims to empower participants and drive social change by addressing power imbalances and fostering critical consciousness [2], [7], [8]. PAR can improve communication, collaboration, and problem-solving within organizations, leading to increased employee engagement and empowerment [1], [5]. PAR has been applied to improve the quality of education and integrate climate change issues into teaching [9], [10]. PAR facilitates organizational transformation, strengthens local leadership, and improves social connections within communities [11], [12].

This research is included in the study of Appropriate Technology. Appropriate Technology (APT) is a concept that emphasizes the use of technology that is appropriate to local social, economic, and environmental

conditions. APPT aims to improve people's welfare in a sustainable and equitable manner. This concept was first widely known through EF Schumacher's book, "Small is Beautiful: Economics as if People Mattered," which criticized industrial technology systems that are environmentally damaging and socially unjust. APPT is often implemented on a small and decentralized scale, which is suitable for small social units in rural areas [13]. Urban agriculture is the practice of growing crops and raising animals in and around cities. This is becoming increasingly important due to limited agricultural land in urban areas and the need to increase food security [14]. Urban agriculture can be carried out through various methods such as hydroponics, aquaponics, and aeroponics, which do not require soil and are more efficient in the use of air and space [14], [15].

Partners (Participants)

The partners in this research were the teachers at Sabilurrosyad Islamic Junior High School, Malang City. The selection of partners was based on an initial needs analysis that identified three key conditions: (1) A progressive and open school vision for STEM (reflected in the "Spesga Technology" program); (2) The existence of pressing factual challenges (limited land space); and (3) The existence of unique local resource potential (the idea of utilizing leftover ablution water). The initial condition of the partners was "ready in terms of vision, but constrained by technical and facility constraints."

Research Procedures (PAR Cycle)

Activities are carried out through four interrelated stages according to the PAR cycle:

Stage 1: Participatory Planning

This stage focused on needs diagnosis and joint problem formulation. The research team conducted audiences and focus group discussions (FGDs) with school leaders and teacher representatives. This dialogue process successfully identified the primary problem (limited land) and generated innovative, contextual ideas from partners, including the idea of utilizing leftover ablution water as a "value anchor" for activities.

Stage 2: Action Design

Based on the agreement in Phase 1, the research team and partners jointly designed a technical solution. It was decided that implementing Appropriate Technology (TTG) in the form of an "Eco Tower Hydroponic" (vertical farming) was the most relevant solution for space efficiency. The research team prepared logistics for the action, including the tower device, pump, growing medium (rockwool), plant seeds, and nutrients (AB Mix).

Stage 3: Implementation of Action and Facilitation

This stage is the core of the intervention. Activities are divided into two sessions:

- Education (Knowledge Transfer): A brief presentation of the basic principles of STEM in hydroponics, the concept of urban farming, and nutrient management.
- Practical Workshop (Skills Transfer): In accordance with PAR principles, the product is not delivered in finished form. Teachers, accompanied by facilitators, are actively involved in the engineering (assembly) process of the Eco Tower from the beginning. This learning-by-doing process includes pipe assembly, pump installation, planting medium preparation, and irrigation systems.

Stage 4: Observation and Reflection

During the workshop (Stage 3), the research team conducted participant observations and recorded field findings (field notes). A critical reflection process was conducted simultaneously with the teachers to evaluate the challenges and successes of the action.

Data Collection and Analysis Techniques

Qualitative data were collected through participant observation, field notes, documentation (photographs), and reflective discussions (FGDs) during the workshop process. Data analysis was conducted using a descriptive-qualitative approach to interpret the competency transformation process, identify crucial findings, and formulate a grounded theory model emerging from the field.

3. RESULTS AND DISCUSSION

3.1. Transforming Partner Roles through Participatory Processes

Key observations revealed a high level of participation and enthusiasm from teachers at Sabilurrosyad Islamic Junior High School during the hands-on workshop. Unlike traditional training models, the PAR approach successfully transformed the role of teachers. They no longer positioned themselves as "objects" receiving materials or grants, but rather as "subjects" actively involved in the problem-solving process. The teachers proactively "got involved" in every detail of the engineering process, from measuring and drilling to

installing the pump system. This enthusiasm indicates a transfer of skills and increased confidence in the technology and engineering domains.

3.2. Implementation of the Hydroponic Eco Tower Prototype



Figure 1. Introduction to AB Mix Nutrition



Figure 2. Seed Preparation and Making AB Mix Nutrients



Figure 3. Assembly Activities

This participatory initiative successfully implemented a functional prototype of the Hydroponic Eco Tower within the school environment. The implementation began with an introduction to AB Mix nutrients, as shown in Figure 1, to help teachers understand the basic role of nutrient solutions in hydroponic cultivation. This vertical farming tower directly addresses the limited land that previously hampered learning practices. With the tower's assembly, the school now has a concrete, functional STEM learning medium that can be used as a "mini laboratory" for science (Biology) and craft practices, while also supporting the school's greening program.

In addition to producing a physical prototype, the implementation phase also demonstrated the practical integration of Science and Mathematics in hydroponic activity. The teachers were introduced to the scientific process of monitoring water quality by measuring pH and PPM values as indicators of nutrient suitability for plant growth. The seed preparation process and the preparation of AB Mix nutrients, illustrated in Figure 2, provided a concrete context for teachers to connect scientific observation with practical cultivation procedures. Through this activity, teachers did not merely observe plant cultivation, but also practiced how scientific data can be collected, interpreted, and used to make decisions, such as adjusting the nutrient solution when the concentration was too low or too high. This process made the Science component visible because teachers directly connected concepts of acidity, nutrient concentration, and plant physiology with real conditions in the Eco Tower system.

The mathematics component was strengthened through practical calculations related to the preparation of AB Mix nutrients. Teachers were guided to determine the amount of nutrient solution needed based on the volume of water available in the reservoir and the target concentration required for hydroponic cultivation. For example, they had to estimate the ratio between water volume and nutrient dosage, compare measurement results with recommended PPM ranges, and calculate the necessary adjustments when the solution concentration did not meet the target. These calculations supported the assembly activities shown in Figure 3, where teachers applied measurement, estimation, and adjustment while constructing the Hydroponic Eco Tower system. These activities trained teachers to apply mathematical reasoning, proportional thinking, unit conversion, and simple quantitative analysis in a concrete context. As a result, the hydroponic Eco Tower became not only a technological product, but also an integrated STEM learning medium in which Science and Mathematics were practiced directly through measurement, calculation, interpretation, and decision-making.

3.3. Critical Findings as a Moment for Engineering Competency Transfer

During the assembly workshop (Stage 3) and simultaneous observation (Stage 4) processes, two unexpected crucial technical findings were identified:

- Logistics Findings: It was identified that the amount of planting media (rockwool) budgeted and prepared was less than the ideal requirement to fill all *the net pots* in the tower.
- Technical Findings (Design): Observations of water flow identified a potential issue. The water flow from the drip irrigation system was deemed uneven and risked not consistently wetting the entire rockwool growing medium.

These two findings, rather than being seen as failures, became pivotal pedagogical moments. The discussion process to solve the technical findings (point b) triggered authentic engineering thinking. The teacher and facilitator jointly analyzed the problem (*troubleshooting*) and formulated a solution hypothesis: the need to add a simple component (flannel) as a capillary *wick* to ensure even moisture distribution.

3.4. Discussion

Validating PAR: Adult Learning (Andragogy) in Practice

The finding of high teacher enthusiasm (Result 1) validates the appropriateness of the PAR methodology chosen, which aligns with the principles of Andragogy (Adult Education). Adult learners (teachers) learn most effectively when they are actively engaged in solving problems that are contextually relevant to their work. By focusing the activity on a real-world problem (a limited space) and involving them in the solution (assembling a tower), this program shifts teachers from passive recipients to active practitioners, which is the essence of continuous professional development.

"Productive Failure": The Essence of Engineering Competency Transfer (STEM)

The technical finding regarding the need for flannel (Result 3) was the most significant finding in this study. If the service team came up with a perfect, zero-defect system, then the only competency transferred would be "operator competency" (how to use it).

However, with the emergence of authentic problems in the field, teachers were "forced" to enter a higher cognitive level: engineering design thinking. They practiced the core engineering cycle: identifying the problem (uneven water), analyzing the root cause (bottleneck), and formulating a solution (flannel hypothesis). This is evidence of the transfer of "E" (Engineering) competencies in STEM, which is often the most difficult domain to teach theoretically. This finding supports the concept of "productive failure," where authentic problem-solving is far more effective for deep learning than perfect direct instruction.

"Value Anchors": Integration of STEM and Contextual-Religious Identity

The success of this program is inextricably linked to the "motivational anchor" identified in Phase 1, namely the idea of utilizing leftover ablation water. This discussion confirmed that in faith-based educational institutions, the implementation of technology (STEM) requires a deeper relevance than simply technical relevance (solutions for limited space).

The idea of utilizing ablation water (anti-waste) gives the technology project its "soul" or "meaning." This aligns with the principles of Contextual Learning (CTL) integrated with Islamic values (the principle of *hifz al-bi'ah*, or environmental stewardship). This "value anchor" transforms the project from a "service project" to a "shared project" aligned with the school's identity and core values.

Program Sustainability and School-Based Maintenance Plan

The sustainability of the Hydroponic Eco Tower program is an important aspect because the success of community service should not stop at the completion of the workshop. After the service activity ended, the school was expected to maintain the unit through a simple school-based maintenance system involving teachers and students. The maintenance plan includes routine monitoring of water availability, checking pump function, observing plant growth, replacing or cleaning the growing medium when necessary, and measuring pH and PPM values to ensure that the nutrient solution remains suitable for plant development. By integrating these tasks into science or project-based learning activities, the Hydroponic Eco Tower can continue to function as a living laboratory rather than becoming a one-time training product.

In practice, the school can assign a small maintenance team consisting of science teachers, student representatives, and members of the school greening or extracurricular program. This team can create a simple weekly schedule for adding water, adjusting AB Mix nutrients, checking the condition of seedlings, and recording measurement results in a monitoring logbook. The logbook can be used by teachers as learning data for classroom discussions, allowing students to analyze changes in plant growth, nutrient concentration, and environmental conditions over time. This strategy strengthens the sense of ownership among school members and ensures that the unit remains useful for continuous STEM learning. Therefore, sustainability is supported not only by the availability of the physical unit, but also by the development of a routine maintenance culture and the integration of hydroponic activities into the school learning ecosystem.

Values-Based Participatory STEM Integration Model

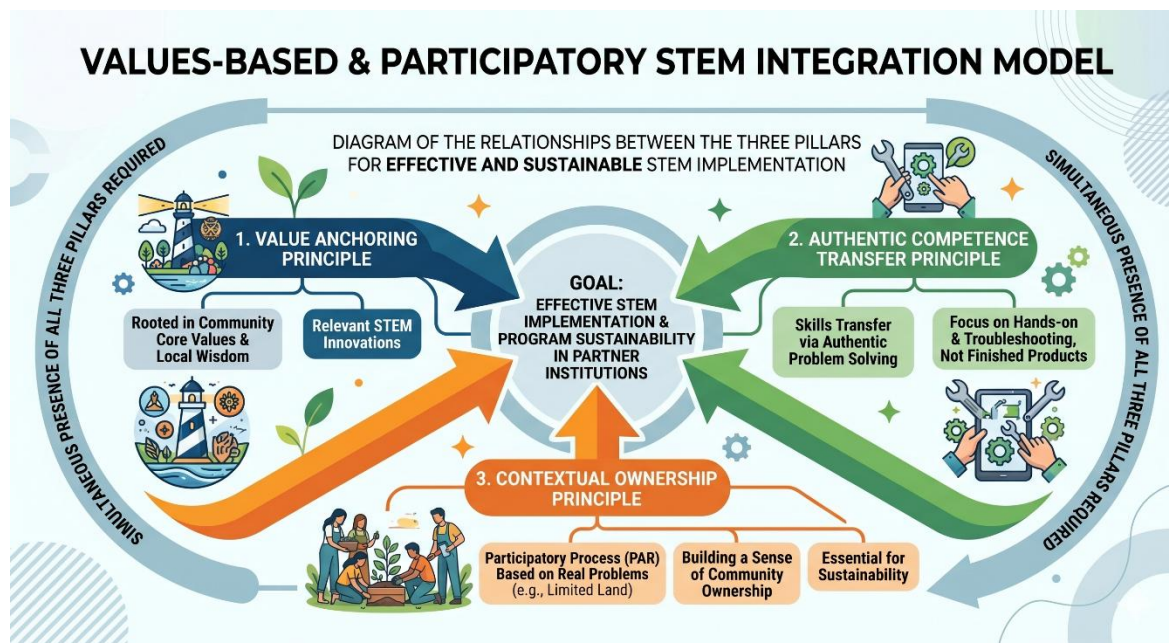


Figure 4. Values-Based and Participatory STEM Integration Model

Based on Figure 4, this study produces a substantive theoretical model for effective STEM implementation in partner institutions, called the "Values-Based Participatory STEM Integration Model." This model stands on three pillars that must be present simultaneously:

1. Value Anchoring Principle: STEM innovations must be relevant and anchored to the core values or local wisdom embraced by the partner community.
2. Authentic Competence Transfer Principle: The focus of the program should be on transferring skills through authentic problem solving (hands-on and troubleshooting), not on delivering a finished product.
3. Contextual Ownership Principle: Participatory processes (PAR) that are relevant to real problems (limited land) will build a sense of ownership that is essential for the sustainability of the program.

4. CONCLUSION

The improvement of practical STEM competencies, particularly in the Engineering and Technology domain, for teachers at Sabilurrosyad Islamic Junior High School has been effectively achieved. This intervention was successful through the application of Participatory Action Research (PAR) methodology centered on a Hydroponic Eco Tower assembly workshop. This medium proved to be a contextual solution to the constraints of limited land. The most important finding is that the participatory technical problem-solving process (troubleshooting) is key to the transfer of authentic engineering competencies. The success of this program is strongly supported by the presence of a "value anchor" (the idea of ablution water utilization) that integrates technological innovation with the school's spiritual identity. This study proposes a "Value-Based Participatory STEM Integration Model" as an effective framework for teacher professional development programs in similar contexts.

5. THANK-YOU NOTE

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