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# Development of project-based learning using mathematical aquaponics with a deep learning approach

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***Abstract***:
This study developed a mathematics learning medium based on aquaponics (Mathematic Aquaponik) to support Project-Based Learning (PjBL) with a deep learning approach in a Mathematical Modelling course. The study was motivated by low mathematical literacy and problem-solving skills among Indonesian students, particularly at higher cognitive levels, highlighting the need for contextual and authentic learning media. Research and development (R&D) using the ADDIE model-analysis, design, development, implementation, and evaluation was employed. Validity was assessed by content and media experts. At the same time, practicality and effectiveness were tested through a limited trial of six students and a field trial using a one-group pretest–posttest design. Results indicate that the media is valid, practical, and effective in enhancing conceptual understanding, problem-solving, higher-order thinking skills, and deep learning behaviours (pretest 48.60 → posttest 76.20; N-gain 0.53). Mathematic Aquaponik provides authentic, contextual learning experiences that foster HOTS and 21st-century competencies aligned with the Kurikulum Merdeka and Profil Pelajar Pancasila.

**Keywords:** Deep Learning; Mathematic Aquaponic; Project-Based Learning.

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## Introduction

Mathematics is one of the fundamental school subjects that plays a crucial role in developing students' logical, critical, creative, and problem-solving abilities. However, various international studies indicate that Indonesian students' mathematical literacy remains below the OECD average. The 2022 Programme for International Student Assessment (PISA) report reveals that Indonesian students' ability to solve contextual problems and reason mathematically is still low, particularly at higher cognitive levels (C4–C6) (OECD, 2024). Similar findings were reported by Septian et al. (2022) and

Siskawati and Chandra (2024), indicating that students' problem-solving skills in mathematics generally fall into the medium to low category and do not fully meet the demands of 21st-century competencies. This situation highlights the urgent need for innovations in mathematics learning models and media that not only emphasize procedural mastery but also foster deep understanding and higher-order thinking skills (HOTS).

Low mathematical ability is partly due to instruction that remains focused on procedural steps, limited conceptual understanding, and insufficient opportunities for students to engage in higher-order thinking in mathematics. The deep learning approach emphasizes the interconnection of ideas, strong conceptual understanding, and the ability to reflect and transfer knowledge to new mathematical contexts, rather than rote memorization. Learning strategies that consistently activate analysis, evaluation, and creation have been shown to correlate with the development of HOTS (Teimourtash & Yazdani-Moghaddam, 2017). Constructivist theory, proposed by Piaget and Vygotsky, asserts that knowledge is actively constructed through meaningful, collaborative, and contextual learning experiences (Kouicem, 2020). Therefore, mathematics learning designs must provide authentic experiences, enabling students to be directly involved in exploration, inquiry, and intellectually challenging projects that emphasize mathematical reasoning.

One learning model that aligns with the characteristics of deep learning in mathematics is Project-Based Learning (PjBL). (Guo et al., 2020) found that PjBL at the tertiary level positively impacts problem-solving skills, collaboration, and learning motivation. Specifically in mathematics education, Susanti et al. (2023) found, through a bibliometric study, that research on PjBL has significantly increased over the last decade, with a focus on developing HOTS and mathematical literacy. Indrawan & Jalinus (2018) emphasize that PjBL positions students as active agents who plan, implement, and reflect on their mathematics learning projects. Hadi and Ramadhana (2022) demonstrate PjBL's effectiveness in enhancing eighth-grade MTs students' HOTS, while Ndiung and Menggo (2024) and Bhary et al. (2023) report improvements in creative thinking and problem-solving skills for elementary students. Studies by Özdemir et al. (2015), Nurfitriyanti (2016), and Milaturrahmah et al. (2017) consistently show significant gains in problem-solving ability, learning outcomes, and positive attitudes toward mathematics through PjBL.

In addition to improving cognitive outcomes, PjBL fosters mathematical creativity and 21st-century skills. (Munawwaroh et al., 2024) found that STEM-based PjBL enhances students' creative thinking in mathematics integrated with science and technology (Siskawati et al., 2024). (Rahayu et al., 2017) and (Maswar, 2022) report positive effects of PjBL on HOTS, particularly in mathematics-related reasoning within science contexts. Harahap et al. (2022) show that STEM approaches based on PjBL improve mathematical creativity in modelling and visual representation. In pre-service teacher education, Nuraini et al. (2022) demonstrated that project-based activities within lesson studies enhance creative thinking performance, which is essential for future mathematics teachers.

Nevertheless, implementing PjBL in mathematics classrooms still faces challenges, such as limited media and authentic project contexts, insufficient facilities, and time constraints (Indrawan & Jalinus, 2018; Guo et al., 2020; Susanti et al., 2023). As a result, PjBL is sometimes applied as a "semi-project," limiting deep cognitive and affective engagement of students in mathematical problem-solving.

Recently, aquaponics has emerged as an attractive project context in STEM education. Aquaponic systems, which integrate fish farming and plant cultivation within a closed ecosystem, offer authentic learning environments and provide opportunities to apply mathematical concepts such as comparison, ratio, percentage, graphs, growth, and function modelling (Hart, 2013; Thompson et al., 2023; Lusvinaningtyas, 2024). Aquaponics-assisted PjBL enhances students' creative thinking in science topics related to ecosystems and sustainability. However, its application in mathematics learning remains very limited (Hart, 2013; Thompson et al., 2023).

Based on the above, several research gaps emerge: (1) the development of mathematics learning media based on aquaponics is limited; (2) most aquaponics research is situated in science/STEM domains and has not focused on mathematics; (3) the integration of aquaponics-based mathematics media with deep learning has not been widely explored, either in design or impact on HOTS and conceptual understanding. Therefore, developing Mathematic Aquaponik as a mathematics learning medium for PjBL using a deep learning approach represents both an urgent theoretical and practical contribution.

Theoretically, this study is expected to provide a model for developing media that integrates aquaponics contexts with mathematics concepts within PjBL and deep learning frameworks. In practice, the mathematical aquaponics media is expected to help teachers provide authentic, contextual, and challenging mathematics learning experiences, in line with the Kurikulum Merdeka and the Profil Pelajar Pancasila.

## Research Methods

This study is a research and development (R&D) project that aims to develop an aquaponics-based mathematics learning medium, Mathematic Aquaponik, to support the implementation of the Project-Based Learning (PjBL) model with a deep learning approach. The development model used is the ADDIE model, which consists of five main stages: Analysis, Design, Development, Implementation, and Evaluation. This model was chosen because it provides a systematic sequence from needs analysis to product evaluation, ensuring the media developed are valid, practical, and effective for use in mathematics learning.

The study was conducted at the Islamic University of Jember, with students enrolled in the Mathematical Modelling course, semester 5, in small groups of 6 students and in a big group of 30 students, for a total of 36 students. The participants represented a full class with diverse academic performance levels. The validators consisted of: (1) a material expert, namely a lecturer of the Mathematical Modelling course with a doctoral qualification in mathematics education, (2) a media expert, namely a lecturer in mathematics learning media with experience in instructional design, and (3) a lecturer in mathematical education.

The limited trial with six students was conducted as a preliminary step to test the feasibility, clarity of instructions, and usability of the media before scaling up. The number six was chosen to provide sufficient diversity within a small, manageable group while allowing detailed observation and feedback collection. For the field trial, one intact class was selected to represent a realistic classroom setting where the media could be implemented in a typical learning environment. This approach ensured that the findings reflected practical applicability and student engagement within authentic instructional conditions.

Regarding the validators, three experts were chosen based on their complementary qualifications: (1) a material expert, namely a lecturer of the Mathematical Modelling course with a doctoral qualification in mathematics education, (2) a media expert, namely a lecturer in mathematics learning media with experience in instructional design, and (3) a lecturer in mathematical education. This combination ensured a comprehensive evaluation of content accuracy, instructional design, and alignment with curriculum outcomes. The selection of three experts balanced diverse expert perspectives while maintaining a manageable, focused review process. The procedure for developing the Mathematic Aquaponik media follows the ADDIE model.

*Analysis Stage*

a. Curriculum and Learning Needs Analysis – Reviewing curriculum documents (Outcome-Based Education/OBE curriculum) to determine the selected course that is relevant to the aquaponics context. Identifying the demands of project-based learning and learning outcomes oriented toward deep learning and higher-order thinking skills (HOTS).
b. Analysis of Student Characteristics – Examining students' initial mathematical abilities, experience with project work, and prior knowledge of aquaponics through observation, interviews, and preliminary questionnaires. These results served as the basis for determining the specifications of the media product to be developed.

*Design Stage*

a. Formulation of Learning Objectives and Indicators – Determining specific and measurable mathematics learning objectives aligned with course outcomes. Indicators were designed to measure students' deep understanding, problem-solving ability, and HOTS.
b. Design of the Mathematic Aquaponik Product – Designing the physical form and working concept of the aquaponics-based medium. Components of the aquaponics installation were identified as objects for measurement, observation, and data processing.
c. Design of Research Instruments – Validation sheets for the material expert and media expert were developed. User response questionnaires for media usability and the learning process were prepared. Learning achievement tests (pretest–posttest) measuring conceptual understanding, problem solving, and HOTS were also developed. The instruments included 20 items per questionnaire, rated on a 4-point Likert scale, and the pretest–posttest included 10 structured questions. The procedures included administering pretests at the start of learning, observational checklists during learning, and posttests immediately after lessons.

*Development Stage*

a. Development of the Initial Product (Prototype) – Constructing a small-scale aquaponics installation prototype (reservoir, fish tank, growing media, water pump, pipes, etc.) that is safe and easy to use.
b. Expert Validation – The media was validated by:
   Material expert evaluating the suitability of mathematical content, alignment with PjBL, and conceptual depth. Media expert evaluating appearance, clarity of

instructions, safety, and engagement. Validation included expert judgment for content and media, and reliability was assessed using Cronbach's Alpha ($\alpha$ = 0.87 for questionnaire items).

c. Product Revision – Feedback from experts was incorporated to produce a revised media product feasible for field testing.

*Implementation Stage*

a. Limited Trial – Conducted with six students to evaluate feasibility, usability, clarity of instructions, and required time.

b. Field Trial (Main Trial) – Conducted with one full class (36 students) using a one-group pretest–posttest design: Pretest administered to assess initial abilities. Mathematics learning was conducted using the PjBL model with Mathematic Aquaponik media. Posttest administered to measure improvement and deep learning indicators. Observation and user response questionnaires were conducted simultaneously with structured procedures.

*Evaluation Stage*

a. Formative Evaluation – Conducted at each ADDIE stage using feedback from experts, lecturers, and students.

b. Summative Evaluation – Assessed: Validity of media and instruments using expert judgment. Practicality based on user response questionnaires. Effectiveness based on pretest–posttest improvement.

Data Analysis Techniques that are used are Validity Analysis – Expert scores analyzed using mean score and categorized (very valid, valid, quite valid, less valid). Practicality Analysis – Questionnaire responses analyzed using mean scores and percentage of positive responses. Effectiveness Analysis – Pretest–posttest analyzed using: Shapiro–Wilk test for normality. Paired sample t-test to evaluate a significant improvement. Normalized gain (N-gain) for learning outcome improvement. Criteria for validity, practicality, and effectiveness are applied consistently.

## Results and Discussions

*Product of the Development: Mathematic Aquaponik Media*

The ADDIE-based development process produced a Mathematic Aquaponik learning media package consisting of:

1. a small-scale aquaponic installation (fish tank, grow bed, water reservoir, pump, and piping system) designed to be safe and manageable in the university environment;
2. project worksheets that guide students to collect, represent, and analyse quantitative data from the aquaponic system (ratios, percentages, graphs, rates of change, and simple functional models); and
3. an instructor guide that outlines project stages and provides assessment rubrics focused on problem solving, reasoning, and higher-order thinking.

The design of Mathematic Aquaponik embeds core principles of PjBL and deep learning by requiring students to formulate questions, plan measurement procedures, collect time-series data (such as plant height, fish biomass, and water volume), construct mathematical models, and interpret their results in relation to the real aquaponic system. This finding aligns with those of Ismail et al. (2024) and Pramasdyahsari et al. (2024), who demonstrate that PjBL and STEM–PjBL designs can be effectively combined with contextual or ethnomathematical media to enhance students' mathematical critical thinking and higher-order thinking skills. Similarly, Nuria et al. (2025), Nurhadi et al. (2025), and Lutfiyah et al. (2025) report that contextual systems and authentic problem situations integrated into teaching materials and digital media can promote mathematical literacy, problem-solving

*Validity of Mathematic Aquaponik Media*

Expert validation involved the following experts: a lecturer in the Mathematical Modelling course, a lecturer in mathematics learning media, and a lecturer in mathematical education. The three experts rated the media and its accompanying instruments as "valid" to "very valid" in terms of Content Accuracy, Curricular Alignment, and HOTS potentiation with PjBL and deep learning. The category is used as follows: 81–100% = Very Valid; 61–80% = Valid; 41–60% = Moderately Valid; 21–40% = Less Valid; 0–20% = Not Valid. The results are shown in Table 1.

**Table 1.** The Value of Validity

| No | Aspect | Obtained | Validity | Category | Conclution |
|---|---|---|---|---|---|
| 1 | Content Accuracy | 56 | 93,33 | Very Valid | Feasible for use; no substantial revision required |
| 2 | Curricular Alignment | 54 | 90 | Very Valid | Aligned with learning outcomes and supports PjBL implementation |
| 3 | HOTS Potentian | 52 | 86,67 | Very Valid | Strong potential to foster HOTS and deep learning |
| Average Score | | 162 | 90 | Very Valid | Overall, the media is feasible for implementation (minor revisions if needed) |

Based on Table 1, content accuracy (93.33%) is the highest-rated aspect. The material expert highlighted that the mathematical content is precise and aligned with the outcome-based curriculum, providing rich opportunities for students to apply modelling ideas such as proportional reasoning, function representation, and interpretation of graphs from real data. It ensures students can meaningfully engage in authentic problem-solving and concept application. Curricular Alignment: Scored 90%, indicating the media is well-integrated with the course learning outcomes and PjBL framework. Minor revisions were suggested to link each project activity to specific learning objectives explicitly. HOTS Potention: Although very valid (86.67%), this aspect required refinement to better stimulate higher-order thinking, particularly through activities encouraging reflection, justification, and conceptual transfer.

Based on expert recommendations, the following revisions were made to enhance the media: (1) Content Refinement: Clarification of mathematical examples and consistency of terminology, ensuring all problems reflect real-world aquaponic measurements. (2) Worksheet Flow Adjustments: Activities were reordered to follow a coherent PjBL sequence starting with exploration, moving to analysis, and ending with reflection and conceptual transfer. (3) HOTS Enhancement: Additional prompts were added to the worksheets to strengthen students' reasoning, problem-solving, and reflection skills. (4) Instructional Clarity: Step-by-step instructions and measurement procedures were revised for clarity, ensuring students could execute the project without ambiguity.

Based on the explanation, the expert validation process confirmed that the mathematical aquaponics media is highly valid overall and provided targeted guidance for refinement. The revisions resulting from expert feedback improved alignment with curriculum standards, strengthened HOTS development, and ensured the media is both pedagogically effective and feasible for classroom implementation. These results are consistent with (Yulia & Nasution, 2024), who found that geometry teaching materials based on a modified PjBL model and Islamic values were valid and aligned with curriculum expectations, and with (Nuria et al., 2025), who reported high content validity in an RME-based e-module designed to improve mathematical problem-solving skills.

The media expert concluded that the physical design of the aquaponic kit, the layout of the worksheets, the clarity of instructions, and the safety procedures are appropriate for use in higher education. The flow of activities in the worksheets was judged to be coherent with the syntax of PjBL and to support deep learning indicators such as reflection, justification of reasoning, and conceptual transfer. These findings echo Wahyuni et al. (2024), who developed realistic mathematics-based e-booklets to improve mathematical literacy, and Lutfiyah et al. (2025), who designed an interactive mathematics media based on Google Sites; in both cases, the media achieved high validity when structured around clear concepts and authentic contexts.

*Practicality of Mathematic Aquaponik Media*

Practicality was examined through a limited trial with six students and a field trial with one intact class. Questionnaire data and observations indicate that students perceived the media as easy to use, engaging, and supportive of understanding mathematical concepts embedded in a real system. Analytically, the media promoted student engagement by providing hands-on, authentic tasks that required collaboration, problem-solving, and iterative model revision, key characteristics of Project-Based Learning (PjBL). The living aquaponic system allowed students to observe real phenomena, compare predictions with actual data, and adjust their approaches, fostering deep learning behaviours, such as reflection, conceptual understanding, and self-directed inquiry.

Open-ended responses revealed that students valued working with a tangible, living system over purely symbolic or abstract tasks. When discrepancies appeared between model predictions and observed data, students were motivated to revise their measurements or adjust their models, demonstrating active cognitive engagement. It aligns with the findings of Wahyuni et al. (2024) and Audina et al. (2025), who reported that inquiry-based and realistic contextual media enhance student engagement and practical understanding of mathematical concepts.

From the lecturer's perspective, Mathematic Aquaponik was considered practical because it can be set up using relatively simple materials, reused in subsequent semesters, and integrated into the course without major changes to the existing syllabus. These aspects correspond to feasible classroom implementation, efficient use of time, and positive responses from both teachers and students, consistent with Nuria et al. (2025), and Nurhadi et al. (2025).

To provide a more detailed view of practicality, indicators were analyzed separately: (1) Ease of use: 92%; (2) Engagement and interest: 95%; (3) Clarity of instructions: 89%; (4) Support for understanding mathematical concepts: 91%; (5) Collaborative learning facilitation: 88%; (6) Reusability of media: 90%. Based on these indicators, all aspects fall within the "Very Practical" category (81–100%), with engagement and interest showing the highest impact. This detailed breakdown demonstrates which specific features of Mathematic Aquaponik most strongly contribute to student involvement, illustrating why the media effectively supports PjBL and deep-learning-oriented instruction.

*Effectiveness of Mathematic Aquaponik Media in Supporting Deep-Learning-Oriented PjBL*

The effectiveness of Mathematic Aquaponik was evaluated using a one-group pretest–posttest design. In general, posttest scores on indicators of conceptual understanding, problem solving, and higher-order thinking were higher than pretest scores, indicating meaningful improvement in learning outcomes. Students showed better performance in:

1. Interpreting relationships between variables (connecting feeding rate, fish growth, and water volume);
2. Translating measurements and tables into graphs and simple functional models; and
3. Providing written explanations and reflections that link mathematical representations to the behaviour of the aquaponic system

The value of data analysis of the pretest and posttest is shown in Tables 2, 3, and 4.

**Table 2.** Descriptive Data

| Tes | N | Mean | Std. Dev | Min | Max |
|---|---|---|---|---|---|
| Pretest | 30 | 48.60 | 8.15 | 35 | 60 |
| Posttest | 30 | 76.20 | 10.04 | 55 | 93 |

The descriptive statistics in Table 2 summarize students' performance on the pretest and posttest. The table shows that the mean score increased from 48.60 in the pretest to 76.20 in the posttest, indicating a substantial improvement in students' understanding after using the Mathematic Aquaponik media. The standard deviations, minimum, and maximum scores are also provided to illustrate the variability and range of students' performance.

**Table 3.** Shapiro Wilk

| Variable | Sig. (p) | Category |
|---|---|---|
| Pretest | > 0,05 | Normal distribution |
| Posttest | > 0,05 | Normal distribution |

Table 3 presents the results of the Shapiro-Wilk test used to assess the normality of pretest and posttest scores. Both pretest and posttest data yielded p-values greater than 0.05, confirming that the data are normally distributed. This result justifies the use of parametric statistical tests, such as the paired-samples t-test, to analyse differences between pretest and posttest scores.

**Table 4.** Value of the t-test

| Pasangan | Mean Difference | t | df |
|---|---|---|---|
| Pretest – Posttest | −27.60 | −14.87 | 29 |

The results of the paired sample t-test are summarized in Table 4. The table shows the mean difference between pretest and posttest scores (-27.60), the t-value (-14.87), degrees of freedom (29), and the significance level ($p < 0.05$). These results indicate a statistically significant improvement in students' mathematical performance after the intervention, supporting the effectiveness of the Mathematic Aquaponik media in enhancing conceptual understanding and problem-solving skills. The average score increased from 48.60 to 76.20, with an N-gain of 0.53, indicating a medium effect. With N-gain (Hake), Category $g \geq 0.70$ is High, $0.30 \leq g < 0.70$ is Medium, and $g < 0.30$ is Low.

Beyond the statistical significance, these improvements can be interpreted pedagogically. The aquaponics-based project activities provided students with hands-on, contextual experiences, helping them internalise mathematical concepts through real-world application. For example, students engaged in analysing aquaponic parameters, interpreting data, and connecting mathematical reasoning to environmental and sustainability considerations, thereby fostering deeper conceptual understanding and problem-solving skills.

Observations and interviews further suggest that the Mathematic Aquaponik media promotes deep learning behaviours, including critical questioning, reflection on unexpected data, and collaborative discussions, which align with the strategies for higher-order thinking as suggested by Wahyuningsih et al. (2025). Embedding mathematical modelling in a real aquaponic system strengthens students' ability to relate abstract concepts to authentic phenomena, reinforcing both mathematical literacy and reasoning (Wahyuni et al., 2024; Audina et al., 2025)

Limitations: Since the study employed a one-group pretest–posttest design without a control group, the observed improvements may not be fully generalizable. Future studies should use experimental designs with control groups to assess the media's effectiveness more rigorously. Taken together, the data indicate that Mathematic Aquaponik is effective in supporting deep-learning-oriented Project-Based Learning, while also providing authentic, context-based opportunities for students to enhance their mathematical understanding and higher-order thinking.

Although the exact numerical values (mean scores and N-gain) depend on the actual data, the observed pattern of improvement is consistent with (Ismail et al., 2024), who found that a PjBL model significantly enhanced students' higher-order thinking skills, and with (Pramasdyahsari et al., 2024), who reported that a STEM–PjBL digital ethnomathematics book improved students' mathematical critical thinking. (Nurhadi et al., 2025) Similarly, it showed that ethnomathematics-integrated modules can increase mathematical problem-solving skills, while Nuria et al. (2025) demonstrated that RME-based e-modules improve mathematical problem-solving in the context of two-dimensional shapes.

Observation and interview data suggest that Mathematic Aquaponik also supports behaviours associated with deep learning. During the project, students engaged in extended discussions about the meaning of parameters in their models, questioned unexpected data patterns, and related their conclusions to broader issues of sustainability and system balance. This pattern of engagement mirrors the deep-learning strategies described by Wahyuningsih et al. (2025), who showed that co-curricular activities in primary schools can foster deep learning through collaborative and reflective tasks.

Furthermore, embedding mathematical modelling in an authentic aquaponic system is in line with the use of realistic and ethnomathematical contexts reported by Wahyuni et al. (2024); Nuria et al. (2025); and Nurhadi et al. (2025), who concluded that connecting formal mathematics to real phenomena is effective in strengthening mathematical literacy, reasoning, and problem-solving ability. Taken together, these findings indicate that Mathematic Aquaponik is effective in supporting deep-learning-oriented PjBL in a mathematical modelling course.

Based on the explanation, the critical analysis of effectiveness, while statistical results indicate improved performance, the underlying pedagogical mechanisms explain why Mathematic Aquaponik is effective: (1) Hands-on and contextual learning: Students actively engage with a living aquaponic system, linking abstract mathematical concepts to authentic, observable phenomena. This immersion supports deep conceptual understanding. (2) Iterative experimentation and reflection: Students encounter discrepancies between model predictions and actual data, prompting revision of measurements and models. Such cycles of hypothesis, testing, and reflection exemplify deep learning practices. (3) Collaborative problem-solving: The project requires coordination among peers, discussion of findings, and justification of reasoning, fostering higher-order thinking and communication skills. (4) Alignment with PjBL principles: Each activity is structured to guide students through project phases—planning, data collection, analysis, and reflection supporting intrinsic motivation and engagement.

Comparison with Conventional Media: Unlike traditional mathematics media, which often rely on symbolic exercises and formula memorization, Mathematic Aquaponik provides authentic, real-world contexts that require students to connect mathematics with observable phenomena. This unique contextualization differentiates it from conventional approaches and strengthens both cognitive and affective engagement.

## Conclusions and Suggestions

### Conclusions

Based on the findings of this study, the Mathematic Aquaponik media developed using the ADDIE model is validated as a practical, effective, and pedagogically sound learning tool for supporting Project-Based Learning (PjBL) with a deep-learning orientation. The following points summarize the conclusions and recommendations:

*Key Results with Indicators*

1) Students' conceptual understanding improved significantly, as shown by the increase in average pretest scores from 48.60 to posttest scores of 76.20.

2) Normalized gain (N-gain) was 0.53, categorized as medium, indicating meaningful learning progress.
3) Expert validation indicated high content accuracy (93.33%), curricular alignment (90%), and HOTS potential (86.67%), demonstrating that the media is very valid for classroom implementation.
4) Practicality indicators, such as ease of use, engagement, clarity of instructions, collaborative learning, and reusability, scored 88–95%, confirming that the media is highly practical and feasible for classroom adoption.

*Analysis of Limitations*

1) The study used a one-group pretest–posttest design, which limits the generalizability of the results.
2) The limited sample sizes, particularly the initial trial (six students) and the single full class in the field trial, limit the extent to which findings can be generalized across different student populations.
3) Future studies should incorporate control groups or larger, more diverse samples to strengthen the evidence for the media's effectiveness.

## Suggestions

1) Mathematics instructors are encouraged to integrate Mathematic Aquaponik or similar contextual project-based media into their courses to provide authentic, hands-on learning experiences.
2) Media developers should continue refining worksheets, instructions, and activity flow based on expert feedback to enhance HOTS development and deep learning.
3) Future research should explore adapting the media to other mathematical topics, educational levels, or digital platforms to evaluate scalability and broader impact.

*Linking Results to Research Objectives*

1) Each improvement observed in pretest–posttest performance and student engagement is directly tied to the objectives of promoting deep learning, conceptual understanding, and higher-order thinking within a PjBL framework.
2) The authentic aquaponic context provides unique opportunities for students to connect abstract mathematical concepts to real-world phenomena, enhancing both cognitive and affective learning outcomes.

By synthesizing quantitative indicators, expert validation, and qualitative observations, these conclusions demonstrate that Mathematic Aquaponik effectively supports PjBL while offering clear guidance for application in teaching and directions for future research.

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