Studies in Learning and Teaching (SiLeT)
Homepage: https://scie-journal.com/index.php/SiLeT
Email: silet@scie-journal.com

p-ISSN: 2722-399X; e-ISSN: 2722-1857
SiLeT, Vol. 6, No. 3, December 2025
Page 768-784
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STEM-Driven Project Worksheets for Teaching Mathematical Concepts in Differential Equations: Development and Impact through the Aquaponics Context

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Article Info

Article history:

Received October 13, 2025
Revised December 11, 2025
Accepted December 28, 2025
Available Online December 31, 2025

Keywords:

Learning outcomes;
Mathematical aquaponics;
Ordinary differential equations;
Project-based learning;
STEM;

ABSTRACT

This study aimed to develop and evaluate the effectiveness of student worksheets based on Project-Based Learning (PjBL) integrated with the STEM approach in the context of mathematical aquaponics for an Ordinary Differential Equations course. The research employed a mixed-methods design using the ADDIE development model, with a quantitative approach through pretest and posttest evaluations and a qualitative approach through observations and a student response questionnaire. Expert validation results indicate that the developed worksheets achieved a high level of validity in terms of content, structure, and language. The implementation of the worksheets involved 10 fourth-semester students of the Mathematics Education program at Hasyim Asy'ari University. Statistical test results show a significant improvement in student learning outcomes after using the STEM-PjBL-based worksheets, with a significance value more than 0.05. Additionally, 88.89% of students gave positive responses to the worksheets, particularly in the aspects of learning motivation, active engagement, and contextual understanding of concepts. These findings indicate that the integration of STEM with PjBL in worksheets within the aquaponic context is effective in improving learning outcomes, critical thinking skills, and student engagement in meaningful mathematics learning.

https://doi.org/10.46627/silet

INTRODUCTION

Mathematics plays a crucial role in everyday life because its concepts enable individuals to understand and solve real-world problems logically. Mathematics is deeply embedded in daily life and serves not merely as a discipline of numbers and procedures, but as a discipline that cultivates critical reasoning and decision-making skills (Khan & Salman, 2020). Early mathematical interventions significantly influence children's numeracy development. For instance, López-Pedersen et al. (2023) demonstrated that a structured early numeracy program yielded moderate gains in number sense and word-problem solving among first graders. Moreover, the application of Realistic Mathematics Education (RME) in primary settings has been shown to enhance both students' problem-solving and critical thinking skills. For example, Amir et al. (2023) found significant improvements in these domains when RME was applied with contextual tasks. In the context of Indonesian elementary education, Septia et al. (2023) reported that applying the Indonesian Realistic Mathematics Education (IRME) approach improved

concept understanding and critical thinking skills in grade 4 students. Furthermore, in secondary education, Sutarni & Gatiningsih (2022) observed that realistic mathematics learning notably increased students' mathematical critical thinking ability across learning cycles. Given the importance of developing critical thinking skills in mathematics education from early childhood to secondary school, this becomes even more relevant as students progress to higher education, where they encounter more complex and abstract mathematical subjects. One such subject is *Ordinary Differential Equations* (ODEs), which not only requires a solid understanding of mathematical concepts but also demands the ability to analyze, reason, and solve problems based on logic and evidence. Therefore, the critical thinking skills cultivated in earlier stages of education serve as a crucial foundation for tackling the conceptual and applied challenges presented in ODEs.

ODEs is a mathematical discipline where critical thinking skills are essential. Critical thinking itself is the ability to solve problems using high-order thinking skills. It is the ability to analyze a situation based on facts and evidence, ultimately concluding a comprehensive thought process (Agnafia, 2019; Rachmatika et al., 2023). It enables students to easily absorb the concepts and information presented by lecturers, raises their awareness of the problems presented, and provides a means for solving them. Through effective learning and practice, students become individuals skilled in critical thinking and problem solving and thus able to make appropriate decisions. This will ultimately contribute positively to their critical thinking skills and learning outcomes.

Learning outcomes entail the process of determining a student's achievement level through assessment activities, reflecting the abilities acquired after learning experiences (Agusti & Aslam, 2022; Gulo, 2022; Nouri, 2025). To achieve learning outcomes that align with learning objectives, a lecturer must design learning activities that suit students' characteristics and learning needs. Effective pedagogical planning plays a key role in ensuring meaningful learning experiences and fostering critical thinking skills (Marudut et al., 2020; Nugraha, 2022; Loughlin & Lindberg-Sand, 2023). On the part of the students, the ability to master the material presented to them can contribute to the achievement of optimal learning outcomes. One way to provide meaningful experiences and instill critical thinking skills in students is by using a learning model that focuses on student activeness. One model that can be used to train students to think critically is the Project-Based Learning model, or PjBL for short. PjBL is a learning model that provides students with the opportunity to design a problem and find their own solutions to the problem, increasing their creativity in doing so.

Project-Based Learning is a learning model oriented toward students—enabling independent learning through problem solving, where students design projects applicable to real life (Ningsih et al., 2021; Niswara et al., 2019; Novalia et al., 2025; Rezkilaturahmi, Retnawati & Setiawan, 2025). Learning with project-based learning makes learning activities more meaningful, allowing students to retain concepts more effectively. Through PjBL, students are encouraged to engage in creative processes and design authentic products, which naturally requires higher-order thinking and fosters critical thinking skills. Additionally, the project-based learning model influenced students' ability to write anecdotal text (Dewi et al., 2023; Herlina et al., 2022; Kokotsaki, Menzies & Wiggins, 2016; Bell, 2010; Septiviana & Abdurrahman, 2024). Project-Based Learning (PjBL) has been shown to enhance students' metacognitive knowledge and their ability to solve complex problems, thereby supporting the development of critical thinking skills and more meaningful learning outcomes (Widodo et al., 2023). Thus, through PjBL, students are encouraged to hone their abilities in these aspects. Optimal outcomes of PjBL can be achieved by integrating it with current educational developments. One such development is the Science, Technology, Engineering, and Mathematics (STEM) approach. STEM integrates four key disciplinary components and has been shown to enhance students' design abilities, creativity, innovation, and problem-solving skills (Kahar & Ili, 2022; Narut et al., 2022; Lou et al., 2017). STEM focuses on solving problems in everyday contexts. It harnesses students' curiosity to help

them understand the material, and it requires students to take responsibility for their own learning activities, thus encouraging critical thinking (Priantari et al., 2020; Khoiriyyah et al., 2022). Previous research has shown that STEM-based guided inquiry learning effectively enhances students' science literacy, highlighting the potential of STEM approaches to improve understanding and application of scientific concepts in classroom settings (Saputro et al., 2023).

STEM allows students to gain a highly beneficial learning experience by systematically integrating knowledge, concepts, and skills. Integrating it with PjBL will provide meaningful experiences for students through project creation (Priantari et al., 2020; Novitasari et al., 2022). In a learning process simultaneously implementing STEM and PjBL, students freely create a project, such as a certain learning activity or producing a product (Novitasari et al., 2022). This research draws upon previous research findings that the average critical thinking skills score of students learning with STEM and PjBL simultaneously was higher than the average of those learning with conventional learning (Narut et al., 2022; Priantari et al., 2020). These findings proved that the integration of the PjBL model with the STEM approach could promote students' ability to generate ideas for solving problems critically and creatively. Others state that the use of the PjBL model could improve student learning outcomes (Lestari, 2021; Qadafi et al., 2022; Nurhayati et al., 2023). Another study found that the STEM approach made the learning process interesting and enjoyable, improving student learning outcomes (Afifah et al., 2021, Wang et al., 2022). STEM-PjBL is an effective pedagogical approach to developing 21st-century skills such as problem-solving, collaboration, and critical thinking through the integration of science, technology, engineering, and mathematics concepts in real-life contexts (Bulu & Tanggur, 2021; Kurniahtunnisa et al., 2023; Rusli et al., 2024; Surti et al., 2023).

Although numerous studies have shown that STEM-PjBL can enhance mathematical skills and critical thinking (Antika, Rusmana, Salsabila & Kohar, 2024; Mustika Sari & Sopiany, 2023; Bulu & Tanggur, 2021), these studies mostly target basic mathematics topics such as fractions or visual mathematical ability, rather than advanced topics like ODEs. To date, no study has integrated STEM-PjBL with a sustainability-oriented context such as aquaponics in the teaching of differential equations.

Based on the explanation above, the researchers were interested in conducting research on how a PjBL model integrated with the STEM approach can improve students' critical thinking skills and learning outcomes using a mathematical aquaponic context. This study aimed to describe the implementation of the STEM-PjBL model and its influence on students' critical thinking skills and learning outcomes in ODEs courses using a mathematical aquaponic system, one of the mathematics learning media with daily life relevance and potential future impact. This medium is not only useful in converting negative mindsets into more positive perspectives; it also has a significant impact on food security and can be used to channel hobbies such as fish farming and gardening in limited space. While aquaponics itself is a method of cultivating fish and plants together in one medium, mathematical aquaponics combines it with mathematical concepts.

Integrating the concept of aquaponics into student worksheets will allow students to apply various mathematical concepts, one of which is modeling the growth of plants and fish, which involves the use of mathematical models that describe changes in water volume over time, influenced by several factors, such as plant growth, fish growth rate, evaporation, and water input. ODEs can be used to predict changes in water volume, which is important for water quality management and growth in pond ecosystems. In addition to differential equations, some other branches of mathematics that can be taught through mathematical aquaponics are geometry in systems design, calculation of proportions in ecosystem balance, and data analysis to monitor plant and fish growth. A number of mathematical aquaponic system illustrations are provided as references for the rest of the paper: Figure 1 is a mathematical aquaponic reference using new equipment, and Figure 2 is a mathematical aquaponic reference using used equipment (Siskawati et al., 2025).

https://doi.org/10.46627/silet.v6i3.749



Figure 1. Mathematical aquaponics using new equipment



Figure 2. Mathematical aquaponics using recycled equipment

This approach not only makes learning more engaging and contextual but also promotes the development of critical thinking, problem-solving, and innovation skills, particularly in the field of sustainable agriculture. Therefore, introducing mathematical concepts through aquaponics constitutes a relevant and significant part of a STEM-based learning strategy that prepares the younger generation to face future challenges. Based on this rationale, the present study aimed to address two research questions: (1) How are the STEM-PjBL student worksheets for teaching ODEs using the aquaponic context? (2) How effective are the developed STEM-PjBL student worksheets in improving students' learning outcomes after participating in learning integrating STEM with PjBL?

RESEARCH METHODS

This study employed a mixed-methods research design, an approach combining quantitative and qualitative methods within a single research process to obtain results that are more comprehensive, valid, reliable, and objective. This approach enables researchers to deeply explore data through qualitative approaches while simultaneously measuring variables statistically through quantitative approaches, thereby providing a more holistic understanding of the research problem (Justan et al., 2024; Mustaqim, 2021). Therefore, this approach is highly relevant for addressing the complexity of educational phenomena that require more than one analytical perspective.

The mixed-methods research design used in this study followed a sequential explanatory design. This type of design integrates quantitative and qualitative methods in a sequential order: the first phase involves the collection and analysis of quantitative data, while the second phase focuses on qualitative data. The quantitative method plays a role in obtaining measurable data, whether they be descriptive, comparative, or associative in nature, while the qualitative method verifies, deepens, expands, weakens, or invalidates the data previously obtained. The research procedure using the sequential explanatory model used in this study is illustrated in Figure 3.

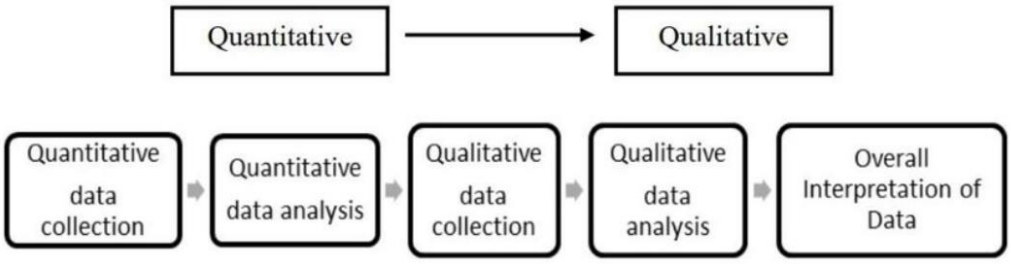


Figure 3. Research process in the sequential explanatory model (adapted from Sugiyono, (2012))

The population in this study consisted of all mathematics education students at Hasyim Asy'ari University, while the sample consisted of 10 students currently enrolled in the ODEs course. The instruments used were the Semester Learning Plan (SLP) for the course, some student worksheets, pretest and posttest questions, and a student response questionnaire.

Quantitative data were first collected from students' pretest and posttest results as well as questionnaires and were analyzed using normality tests, hypothesis testing (t-test), and descriptive analysis of student responses. These results provided a general picture of the effectiveness of the STEM-PjBL worksheets using the aquaponics context. Subsequently, qualitative data were collected during the development process of the worksheets using the ADDIE (Analysis, Design, Development, Implementation, Evaluation) model and analyzed using qualitative descriptive techniques. The qualitative findings were then used to explain and interpret the quantitative results, offering a deeper understanding of how the worksheets influenced students' critical thinking skills and learning outcomes. By structuring the study in this sequential manner, the researchers were able to obtain a comprehensive and well-integrated understanding of both the effectiveness and the developmental process of the STEM-PjBL worksheets.

The quantitative data analysis followed the steps of the normality test analysis. The steps of the normality test were as follows (Rodliyah, 2021):

1. The observed data were arranged from the smallest to the largest value.
2. From these values, a relative cumulative frequency distribution was constructed, denoted as Fa(Y) = $\frac{fk}{n}$.
3. The value of Z was calculated using the formula $Z = \frac{Y-\bar{Y}_1}{S}$, where $\bar{Y}$ is the mean and S is the standard deviation.
4. The theoretical cumulative frequency distribution or expected frequency was then calculated and denoted as Fe(Y), obtained from the normal distribution table.
5. The absolute difference between Fa(Y) and Fe(Y), denoted as D, was determined.
6. The maximum value of D was compared with the critical value: D_{max} = max|Fa(Y)-Fe(Y)| with $\alpha = 0.05$. D_{table} = D (0.05;n), with α = 0.05 and n representing the sample size.

   A decision was made using the criteria below:

   - If $D_{max} \leq D_{table}$, then H_0 was accepted, meaning that the data were normally distributed.
   - If $D_{max} > D_{table}$, then H_0 was rejected, meaning that the data were not normally distributed.

https://doi.org/10.46627/silet.v6i3.749

If the data used were normally distributed, the next step was to conduct hypothesis testing using the t-test as follows:

1. Ho: STEM-PjBL using student worksheets with the context of Mathematical Aquaponics is not effective in improving student learning outcomes in the ODEs course.
2. H1: STEM-PjBL using student worksheets with the context of Mathematical Aquaponics is effective in improving student learning outcomes in the Ordinary Differential Equations course.
3. Significance level, α = 0.05
4. Reject H_0 if $t > t_{\frac{\alpha}{2};v}$
5. Calculating the t-value:

   Mean Difference $(\overline{D}) \rightarrow \quad \overline{D} = \frac{\sum_{i=1}^{n} D_i}{n}$

   Standard Deviation $(\boldsymbol{S_D}) \rightarrow \quad \boldsymbol{S_D} = \sqrt{\frac{n\sum_{i=1}^{n} D_i^2 - \left(\sum_{i=1}^{n} D_i\right)^2}{n(n-1)}}$

   Test statistic to evaluate $H_0 \rightarrow \quad \boldsymbol{t} = \frac{\overline{D} - \mu_0}{\frac{S_D}{\sqrt{n}}}$

   where degrees of freedom, $v = n - 1$
6. Drawing conclusions

   In this study, the normality test and hypothesis testing were conducted using SPSS Version 25.

RESULTS AND DISCUSSION

Analysis Stage

At this stage, a needs analysis was conducted for the ODEs course in the Mathematics Education study program at Hasyim Asy'ari University. Based on observations, it was found that (1) students still had difficulty understanding abstract concepts in ODEs, especially in real-world applications; (2) learning activities tended to be lecturer-centered and lacked contextual exploration; and (3) previous learning had never applied the PjBL model or interdisciplinary integration (STEM approach). Furthermore, the analysis of student characteristics showed that students had diverse backgrounds in advanced mathematics mastery and were generally unfamiliar with the STEM approach explicitly.

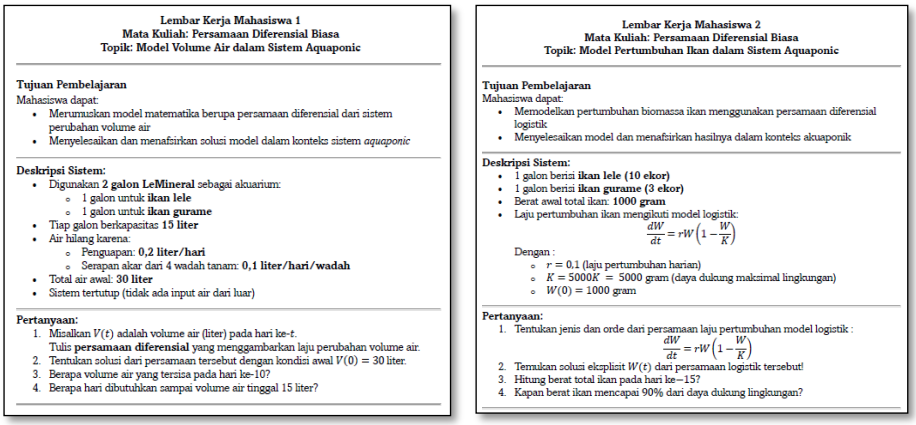
Design Stage

The design of the student worksheets was based on a PjBL approach integrated with STEM components: Science (basic knowledge of the aquaponic system), Technology (use of pH, temperature, and water flow monitoring tools), Engineering (design of the flow system), and Mathematics (mathematical modelling using differential equations).

Several aspects designed in this stage were as follows:

- Learning objectives based on graduate learning outcomes.
- Project activity flow: problem identification → aquaponic system design → mathematical modelling → results interpretation.
- Student worksheet structure: consisting of introduction, learning objectives, system description, activities, reflection, and evaluation.

The design also considered the connection between ODEs topics such as first-order differential equations, separation of variables, and applications of rate of change in closed systems (see Figure 4).



Lembar Kerja Mahasiswa 1
Mata Kuliah: Persamaan Diferensial Biasa
Topik: Model Volume Air dalam Sistem Aquaponic

Tujuan Pembelajaran
Mahasiswa dapat:
- Merumuskan model matematika berupa persamaan diferensial dari sistem perubahan volume air
- Menyelesaikan dan menafsirkan solusi model dalam konteks sistem *aquaponic*

Deskripsi Sistem:
- Digunakan **2 galon LeMineral** sebagai akuarium:
  - 1 galon untuk **ikan lele**
  - 1 galon untuk **ikan gurame**
- Tiap galon berkapasitas **15 liter**
- Air hilang karena:
  - Penguapan: **0,2 liter/hari**
  - Serapan akar dari 4 wadah tanam: **0,1 liter/hari/wadah**
- Total air awal: **30 liter**
- Sistem tertutup (tidak ada input air dari luar)

Pertanyaan:
1. Misalkan $V(t)$ adalah volume air (liter) pada hari ke-t.
   Tulis **persamaan diferensial** yang menggambarkan laju perubahan volume air.
2. Tentukan solusi dari persamaan tersebut dengan kondisi awal $V(0) = 30$ liter.
3. Berapa volume air yang tersisa pada hari ke-10?
4. Berapa hari dibutuhkan sampai volume air tinggal 15 liter?

Lembar Kerja Mahasiswa 2
Mata Kuliah: Persamaan Diferensial Biasa
Topik: Model Pertumbuhan Ikan dalam Sistem Aquaponic

Tujuan Pembelajaran
Mahasiswa dapat:
- Memodelkan pertumbuhan biomassa ikan menggunakan persamaan diferensial logistik
- Menyelesaikan model dan menafsirkan hasilnya dalam konteks akuaponik

Deskripsi Sistem:
- 1 galon berisi **ikan lele (10 ekor)**
- 1 galon berisi **ikan gurame (3 ekor)**
- Berat awal total ikan: **1000 gram**
- Laju pertumbuhan ikan mengikuti model logistik:
$$\frac{dW}{dt} = rW\left(1 - \frac{W}{K}\right)$$
Dengan :
  - $r = 0,1$ (laju pertumbuhan harian)
  - $K = 5000K = 5000$ gram (daya dukung maksimal lingkungan)
  - $W(0) = 1000$ gram

Pertanyaan:
1. Tentukan jenis dan orde dari persamaan laju pertumbuhan model logistik :
$$\frac{dW}{dt} = rW\left(1 - \frac{W}{K}\right)$$
2. Temukan solusi eksplisit $W(t)$ dari persamaan logistik tersebut!
3. Hitung berat total ikan pada hari ke−15?
4. Kapan berat ikan mencapai 90% dari daya dukung lingkungan?

Figure 4. The student worksheets developed using STEM-PjBL in the context of mathematical aquaponics

Development Stage

Based on the initial design, the student worksheets were developed using communicative language and appealing visualizations of an aquaponic system. The student worksheets were prepared in a printed format to support flexible use. The developed student worksheets were validated by three material experts. The validation results indicated that the student worksheets fell into the very valid category, with only minor revisions suggested in the learning activity section (see Table 1).

Table 1. Result of expert validation of the student worksheets

Review	Aspects Evaluated	Score from Validator			Average per Aspect	Average per Review
		1	2	3		
Content	The material presented aligns with the learning outcomes of the ODEs course.	4	4	4	4	4.3
	The mathematical concepts used in the worksheets are accurate and appropriate.	4	4	5	4.333	
	The mathematical content is relevantly linked to the aquaponic context.	4	4	4	4	
	The depth of the material is appropriate for the targeted student level.	4	5	4	4.333	
	The material enhances contextual understanding of mathematical concepts.	5	5	4	4.667	
Construct	The worksheets are systematically structured based on the stages of project-based learning.	4	5	5	4.667	4.5
	STEM elements (science, technology, engineering, and mathematics) are clearly and evenly integrated into the project activities.	4	4	5	4.333	
	The structure and flow of activities are logical and easy to follow for students.	4	4	4	4	
	The worksheet encourages the development of critical thinking and problem-solving skills.	4	5	5	4.667	
	The activities promote collaboration among students and independence in task completion.	5	5	5	5	

Review	Aspects Evaluated	Score from Validator			Average per Aspect	Average per Review
		1	2	3		
Language	The instructions and guidelines in the worksheets are clearly stated and easy to understand.	4	5	4	4.333	4.7
	The language used is appropriate for students' proficiency level and background.	5	5	4	4.667	
	Grammar and spelling are accurate and consistent throughout the worksheets.	5	5	5	5	
	Technical and mathematical terms are used consistently and accurately.	5	5	4	4.667	
	The language is free from ambiguity, ensuring clarity for students.	5	5	5	5	
	Average Score from Each Validator					4.5
	Conclusion					**Very Valid**

Based on the feedback from the validators, the researcher revised the student worksheets. The revisions made are described in Table 2.

Table 2. Revisions made to the student worksheets

Validator Feedback	An explanation of equation categories should be provided in the student worksheets.
Before Revision	There was no explanation indicating that the given equation is a non-homogeneous differential equation.
After Revision	An explanation indicating that the given equation is a non-homogeneous differential equation was added.

Implementation Stage

The student worksheets were implemented with fourth-semester students of the Mathematics Education study program at Hasyim Asy'ari University, who were taking the ODEs course. The implementation activities were carried out over three sessions, using a mixed method of individual and group work. The implementation steps were as follows:

1. Introduction to the aquaponic concept and project explanation.
   Students, in groups, collaboratively built an aquaponic system with assistance from an expert in the field. After the lecturer introduced the concept of differential equations within the context of the aquaponic system project, the students, supported by the technical expert, worked together to build the aquaponic system project. Below are the design and the product of the aquaponic system created by the students, assisted by the technical expert (see Fig. 4).



Figure 4. The design of the aquaponic system and the resulting product created by the students and the technical expert

2. Students completed the student worksheets related to a simple aquaponic system.
3. Students developed a differential equation model based on the phenomenon observed in the worksheets.
4. Presentation and discussion of project results.
5. Evaluation Stage

The evaluation was conducted in two forms:

a. Learning Outcome Evaluation

A pretest and posttest were conducted to measure the improvement in students' understanding of the concept of ODEs (see Table 3).

Table 3. Average pretest and posttest scores of students

Subject	Pretest	Posttest
M1	30	80
M2	20	80
M3	10	90
M4	10	70
M5	30	70
M6	20	70
M7	30	80
M8	30	90
M9	20	80

The result showed a significant difference in students' learning outcomes after using the STEM-PjBL-based worksheets. The results of the normality test of the pretest and posttest data are presented below:

Table 4. Normality test results

Category	**Sig.**	**Decision**	**Description**
Pretest	0.059	Ho was accepted	Normal
Posttest	0.200	Ho was accepted	Normal

As presented in Table 4, the results of the normality test using the Kolmogorov-Smirnov method show that the significance value (sig) of the pretest was 0.059, which was greater than 0.05. This suggests that H_0 be accepted and be rejected, meaning that the data were normally distributed. Meanwhile, the significance value of the post-test was 0.200, which also exceeded 0.05, suggesting that it be accepted and be rejected, and thus the data were assumed to be normally distributed. It can be concluded that the post-test results in both classes show normally distributed data. Based on the results of the prerequisite analysis, which indicate that the data were normally distributed, the next step was to conduct a statistical hypothesis test. The pre-test and post-test data of the students were used for further analysis using the paired sample t-test. The results of the hypothesis testing are presented in Table 5.

Table 5. Hypothesis Testing Results

Category	**Sig.**	**Decision**	**Description**
Pretest-Posttest	0.000	H_1 was accepted	Effective

As shown in Table 5, the significance value obtained was 0.000 (more than 0.05), suggesting that it be rejected and be accepted. This means that there was a significant difference in student learning outcomes before and after STEM-PjBL implementation using the developed student worksheets. These results indicate that STEM-PjBL using the developed student worksheets within the context of mathematical aquaponics was effective in improving student learning outcomes in the Ordinary Differential Equations course.

b. Student Response Evaluation

Most students stated that the developed student worksheets helped them in: (1) Understanding the real-world applications of the ODEs material, particularly on homogeneous differential equations; (2) Increasing learning motivation; and (3) Working more collaboratively and creatively. The results of the student response questionnaire after students received STEM-PjBL within the context of mathematical aquaponics can be seen in Table 6.

Table 6. Student response questionnaire results

No.	Aspect	% Response Positive	% Response Negative
1.	Learning Motivation	88.89%	11.11%
2.	Active Engagement in Learning	88.89%	11.11%
3.	Contextual Understanding of Mathematical Concepts	88.89%	11.11%
4.	Collaboration Skills	88.89%	11.11%
5.	Problem-Solving Ability	88.89%	11.11%
6.	Response to Aquaponics Media as a STEM Context	88.89%	11.11%
	Average	88.89%	11.11%

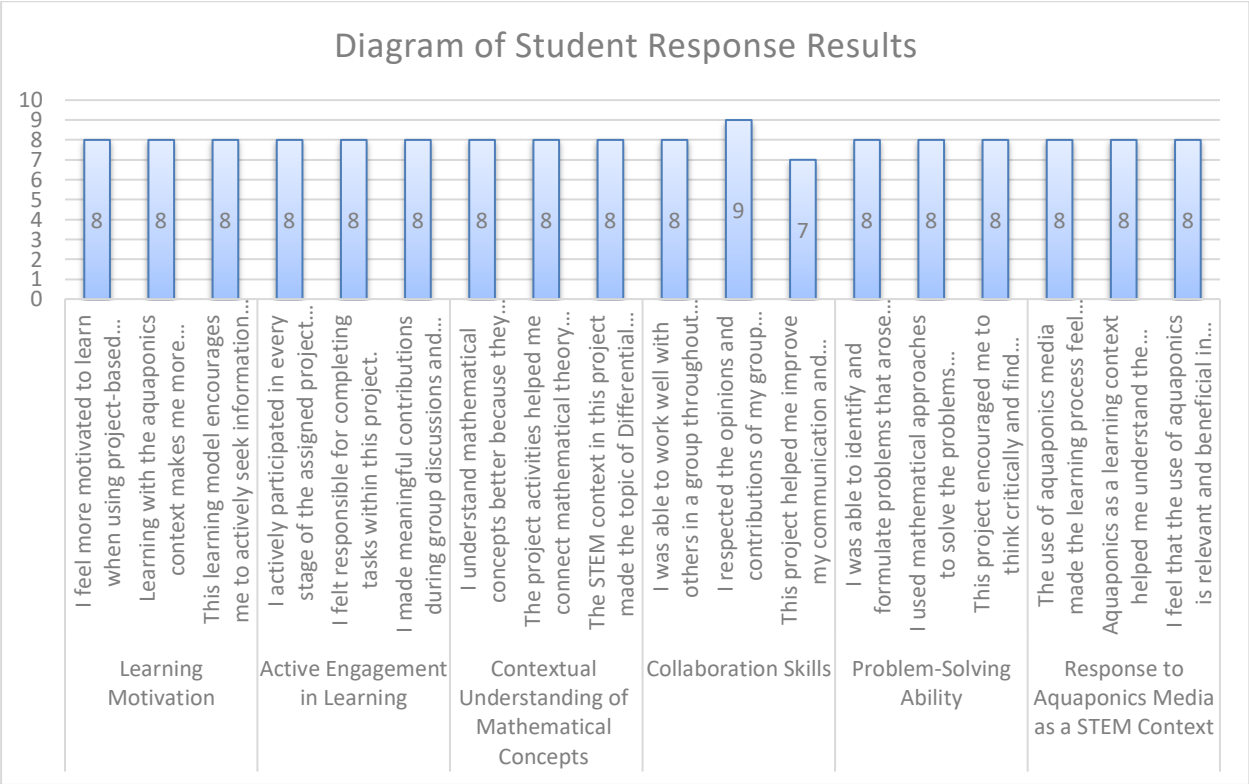


Figure 5. Diagram of student response questionnaire results showing positive responses in six aspects to the student worksheets and STEM-PjBL within the context of mathematical aquaponics.

For more clarity, the results of the student response questionnaire showing positive responses in six aspects to the developed student worksheets and STEM-PjBL within the context of mathematical aquaponics can be seen in the diagram presented in Figure 5.

Discussion

The findings of this study indicate that the use of the student worksheets integrating the STEM-based PjBL model within the context of mathematical aquaponics was effective in improving students' learning outcomes in the ODEs course. The significant improvement demonstrated through the statistical analysis of pretest and posttest results suggests that students not only gained better conceptual understanding but were also more capable of connecting abstract mathematical concepts to real-life situations. This aligns with the findings of Roslina et al. (2024), who reported that the STEM-based PjBL model enhances problem-solving skills and provides meaningful learning experiences through real-world contexts, such as alternative energy and environmental issues. Similar findings are reported in international contexts, where STEM-PjBL approaches improve students' mathematical understanding and problem-solving skills in higher education. For instance, Becker & Park (2011) conducted a meta-analysis and found that integrative STEM approaches significantly enhanced learning outcomes and engagement.

Using aquaponics as a learning context offers a distinct advantage, as it enables the holistic integration of science, technology, engineering, and mathematics concepts. Students are encouraged not only to understand differential equations theoretically but also to apply them to model dynamic systems in closed ecosystems such as aquaponics. This approach allows them to build mathematical models to represent variables such as fish growth rate, plant development, and water volume regulation, which are real-world applications of first-order differential equations. This finding is in line with Capraro and Slough's (2013) perspective that project-based learning integrated with STEM fosters authentic learning environments, increases motivation, and cultivates 21st-century skills such as critical thinking, collaboration, and innovation.

Several recent meta-analyses and systematic reviews confirm that STEM-PjBL significantly improves student learning outcomes, engagement, and higher-order thinking across diverse educational levels (Auliyani, Arianto & Kholidya, 2025; Agustin et al., 2022; Nova et al., 2024). In particular, studies show that STEM-PjBL enhances problem-solving skills and motivation (Roslina, Liliawati & Hasanah, 2024; Maryanti, Kusumaningrum & Mardhatillah, 2025), and when contextualized in real-world or environmental topics, it can foster broader competencies such as environmental literacy and engineering literacy (Pertiwi, Oetomo & Sugiharto, 2024; Nova et al., 2024).

In addition to improving learning outcomes, the study also revealed that nearly all students responded positively to the implementation of the student worksheets that integrated STEM-based PjBL. A total of 88.89% of students reported feeling more motivated and actively engaged in discussions and project practices and found it easier to understand mathematical concepts in context. This is supported by the findings of Monika et al. (2023) that STEM-PjBL was significantly more effective than STEM-PBL in enhancing students' critical thinking skills and engagement in the learning process. The students' involvement in constructing the aquaponic system further enriched their learning experience, as they were not merely recipients of information but also acted as designers and active participants in applying mathematical concepts.

Expert validation of the developed worksheets showed a high level of validity in terms of content, structure, and language. This strengthens the claim that the instructional material was appropriate and aligned with the characteristics of the students and the learning objectives. Similarly, Wandani et al. (2024) demonstrated that content-valid STEM-PjBL-based learning media effectively promoted students' mathematical communication skills. The relevance of the content to everyday life contexts emerged as a key factor in increasing student engagement and understanding.

Nevertheless, this study has several limitations that should be acknowledged. The relatively small sample size (only 10 students) restricted the generalizability of the findings. Therefore, future studies with a broader scope and multisite approach are highly recommended. Additionally, the short implementation duration made it difficult to assess the long-term effects of project-based learning on concept retention and the transferability of critical thinking skills to

other contexts. Future research could also explore how this approach influences non-academic aspects, such as leadership, project management, and communication skills, which are highly relevant in preparing graduates to meet the demands of the Fourth Industrial Revolution.

Overall, this study has demonstrated that integrating STEM into project-based learning models packaged in the form of contextual student worksheets, such as those based on aquaponics, holds great potential for enhancing the quality of mathematics education in higher education. This approach not only brings mathematics closer to real life but also fosters essential skills that students need to face global challenges, particularly in the fields of applied science and technology.

CONCLUSION

Based on the research findings and data analysis, it can be concluded that the use of student worksheets based on Project-Based Learning (PjBL) integrated with the STEM approach in the context of mathematical aquaponics is effective in improving student learning outcomes in the ODEs course. The significant improvement in pretest and posttest scores indicates that this approach helps students understand abstract concepts in a more concrete and applicable manner. The aquaponic context provides an authentic learning experience and enables students to develop 21st-century skills, such as critical thinking, problem-solving, and collaboration. The high validity of the developed worksheets, along with the positive responses from the majority of students, reinforces the relevance of this approach in higher mathematics education. These findings suggest that integrating STEM with PjBL in a real-world context can serve as a model for developing instructional materials that enhance both conceptual understanding and essential skills required in higher education. Educators can adopt similar approaches to bridge theoretical knowledge with practical applications, fostering student engagement and lifelong learning. Nevertheless, the limited sample size and short implementation duration are important considerations. The study's findings may not be generalizable to larger populations or different educational contexts, and long-term retention of knowledge and skills was not assessed. Recommendations for Future Research: Future studies are recommended to be conducted with a broader scope, longer duration, and more diverse student populations to evaluate the long-term impact of STEM-based PjBL worksheets on learning outcomes and the transfer of critical thinking skills. Additionally, research could explore their effects on non-academic competencies, such as leadership, collaboration, and project management skills, which are crucial for the 21st-century workforce. Overall, the integration of STEM into a project-based learning model using a mathematical aquaponic context provides a meaningful contribution to enhancing contextualized mathematics education and preparing students to apply mathematical concepts in real-life scenarios.

ACKNOWLEDGEMENTS

The research team extends profound gratitude to the Institute for Research and Community Service (LPPM) of Hasyim Asy'ari University, Tebuireng, Jombang, for the moral and material support provided. The funding assistance provided by the LPPM has made a significant contribution to the smooth progression of this research up to the stage of scientific article preparation. It is hoped that this collaboration and synergy continue to flourish with the advancement of scientific knowledge in the future.

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