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Research Article

Learning Sustainable Agriculture through Mathematics: Development of a Project-Based Learning Package in Teaching Mathematics for Grade 10 Level

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Abstract

This study explores the integration of sustainable agriculture concepts into mathematics education through the development of a project-based learning package for Grade 10 students. The goal is to enhance students' 21st-century skills while demonstrating the relevance of mathematics to real-life applications. Using thematic analysis of data gathered from interviews with three agricultural experts and three experienced mathematics teachers, the study identified key themes that interconnect sustainable agriculture and mathematical concepts. The findings highlight that sustainable agriculture can serve as a practical context for learning mathematics, fostering both critical thinking and problem-solving skills. This interdisciplinary approach bridges theoretical knowledge with practical application, enriching mathematics education by embedding it in meaningful, real-world scenarios. It also contributes to sustainable agriculture education by promoting awareness and skills essential for addressing global sustainability challenges. Future research should explore broader agricultural concepts and their potential mathematical connections to further enhance interdisciplinary learning opportunities.

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Introduction

Mathematics is one of the indispensable academic disciplines in the school curriculum and is also helpful in our daily lives and other subject areas. However, mathematics is often taught to focus on oversimplified and unrealistic textbook problems that do not mirror real-life situations (Dalton, 2017). This can lead to a disconnection between the math being learned and its real-world applications, which makes it difficult for students to see the relevance and value of the material. In line with this, student performance is affected by numerous factors, such as students' attitudes toward mathematics, teachers' instructional methods, and the school environment (Mazana et al., 2018).

Mathematics can be so difficult that students would feel unmotivated to learn it due to its complexity. According to the Department of Education's National Report of the Philippines, the Philippines had the lowest mean scores of participating ASEAN countries vis-à-vis the OECD average in mathematical literacy. As mentioned in the PISA 2018 International Report (OECD, 2019), Filipino students scored 353 points on average, which is much lower than the OECD average (489 points) and is regarded as below Level 1 proficiency (358 is the lower cut score for Proficiency Level 1). This means that most Filipino students can barely answer questions using familiar contexts when all relevant information is present, and the questions are well specified. They cannot identify information in specific contexts and carry out routine tasks based on direct instructions. Also, they cannot take actions that are virtually always clear and follow promptly after being presented with stimuli (OECD, 2019).

However, teaching math from a different angle can drive students' interest in learning when they can see the relevance of these mathematical concepts to their lives outside the classroom. In a study by Hizon (2019), using real-world problems and contextualized teaching materials is effective and efficient for teachers. On the other hand, students find them to be a tool for understanding, loving, and enjoying mathematics. Hence, the best way to teach mathematics is to provide students with relevant experiences by solving problems they encounter regularly (Laurens et al., 2017).

The study is guided by the contextual learning theory (Johnson, 2002) which posits that learning occurs most effectively when it is tied to real-life contexts. By embedding mathematical concepts within the framework of agriculture, students are able to relate abstract ideas to familiar, meaningful applications. This approach enhances student engagement and retention, as learning is perceived as relevant and valuable beyond the classroom. Contextualization is one of the keys to engaging students in the teaching-learning process because it enables students to connect their experiences and teachings. The lesson becomes engaging and pertinent to the student's life when it is connected to the student's context through school-taught mathematics (Reyes et al., 2019). Also, contextualized education has been demonstrated to effectively teach mathematical computation, giving learners more comprehensive access to the mathematics curriculum (Reyes et al., 2019).

PjBL is a systematic approach to teaching and learning that includes learners participating in complex, real-world projects resulting in finished products or presentations before an audience, allowing them to acquire knowledge of relevant skills (Chen & Yang, 2019). Siswono et al. (2018) found that students are enthusiastic about working on a given topic and openly discussing it with their groups. In order to help students improve their critical thinking, creativity, communication, and cooperation skills and their overall attitude towards mathematics, they suggested that teachers include PjBL in other math courses. In addition, one way of helping pupils understand and

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appreciate the mathematical concepts they have learned in school may be by integrating mathematics into other areas.

Despite growing evidence supporting contextualized learning, there is limited research explicitly connecting mathematics education with sustainable agriculture—a field that is increasingly important in addressing global challenges such as food security and environmental sustainability. While studies like those by Hizon (2019) and Laurens et al. (2017) emphasize the benefits of using real-world problems in mathematics education, they do not explore how agriculture, particularly sustainable practices, can serve as an authentic and meaningful context for learning mathematical concepts.

This study addresses this gap by developing a project-based learning (PjBL) package that integrates sustainable agriculture into the teaching of mathematics. By doing so, it offers a novel interdisciplinary approach that not only enriches mathematics education but also promotes awareness of sustainable agricultural practices among students. This approach responds to the need for educational strategies that prepare students for complex global challenges while fostering essential 21st-century skills such as critical thinking, problem-solving, and collaboration. Moreover, the study identifies least-learned mathematical competencies and designs targeted activities to address these areas, providing a practical model for enhancing both mathematical and interdisciplinary education.

By bridging the gap between mathematics and sustainable agriculture, this research contributes to the literature on contextualized learning and offers educators a concrete framework for integrating real-world applications into mathematics instruction. This not only enhances students' appreciation for mathematics but also equips them with the skills and knowledge needed to contribute meaningfully to sustainable development.

Materials and Methods

The Materials and Methods are presented here. Ensure that all the data, materials, and protocols related to the article are made available to the readers. If the data set used for the study is large and cannot be included in the article, then ensure that it is deposited to publicly available databases or information, share the sources, and provide relevant information to access the data. Additionally, if the nature of the study requires ethical approval, like a study in animals or an experiment involving humans, ensure that the information about the ethical approval is provided.

Research Design

The nature of this study is a qualitative-developmental research design. According to Denzin & Lincoln (2008), qualitative research is intended to give the researchers a way to comprehend a phenomenon by observing or interacting with the study participants. Hence, qualitative research has the potential to generate detailed descriptions of the participants' thought processes and typically focuses on the reasons why a phenomenon occurred (Creswell, 2003). Moreover, according to Ritchey (1994), developmental research has been characterized as the systematic study of designing, developing, and assessing instructional programs, procedures, and products that must meet internal consistency and effectiveness requirements. In addition, developmental research can produce generalizable findings, legal conclusions, or context-specific knowledge that aids in issue-solving (Richey & Klein, 2005). The

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study's methodological framework is presented in figure 1.

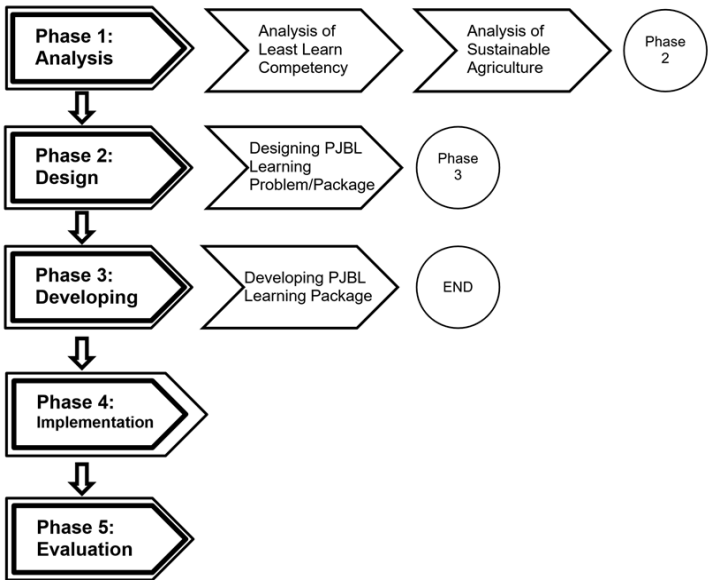

Figure 1. ADD Model

The developmental model used in this study refers to the ADDIE model created by the Center of Educational Technology at Florida State University. This model includes five stages: 1) the Analysis stage, 2) the Designing stage, 3) the Development stage, 4) the Implementation stage, and 5) the Evaluation stage. However, the researchers will only use the Analysis, Designing, and Development part of the ADDIE model in creating the learning package. The first phase (analysis phase) was carried out based on the information obtained from the interviews with experts and teachers. The feedback from the respondents was examined for their applicability to the prototyping of the teaching-learning package. In the subsequent phase (design stage), the relevant answers from the interviews were incorporated into the planning and development of the further development and implementation of the prototype. Once the design phase is complete, the third phase of the (development phase) involves including a series of more detailed and complex tasks and activities, as well as specific instructions for teachers and students.

Participants

The participants of this study are the Grade 10 teachers of Davao City National High School (DCNHS) and experts in the field of agriculture. The researchers selected three Grade 10 teachers out of fourteen Grade 10 mathematics teachers and three experts in agriculture. There are criteria that the teachers and experts should meet in order to be selected. Teachers should have at least five years of service and have experience creating self-learning modules in Grade 10 mathematics. Correspondingly, experts should know about urban farming or whose profession is in agriculture. Table 1 and Table 2 shows the profile of the study participants.

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Table 1. Agricultural Experts Profile

Participant	Designation
Agricultural Expert 1	Founder of Urban Container Gardening
Agricultural Expert 2	Home Farming Practitioner
Agricultural Expert 3	Home Farming Practitioner

Table 2. Educational Experts Profile

Participant	Designation	Years in Service
Education Expert 1	Master Teacher I	11 years
Education Expert 2	Teacher III	10 years
Education Expert 3	Master Teacher II	14 years

The study utilized Focus Group Discussion (FGD) with teachers and In-Depth Interviews (IDI) with experts to ensure the data collected is high quality. Through FGD, the researchers can achieve detailed, high-quality, deeper, and richer data than one-on-one interviews (Gundumogula, 2020). On the other hand, IDI helps gather detailed information from a participant's thoughts, perspectives, and experiences on a particular situation or idea.

Instrument

In this study, the researchers utilized interviewing strategies. As described by Adhabi and Anozie (2017), interviewing is a form of consultation where the researchers seek to know more about an issue as opinionated by the individual being asked. In simple terms, interviewing is a method of gathering information through direct or indirect conversation with an individual or a group. In this study, researchers interviewed the participants with open-ended questions, actively listened to the interviewee, and avoided leading or biased questions to create a comfortable and safe environment for the interviewee. Overall, to get the appropriate data needed, the research instrument of this study consists of open-ended questions that are used for the interview and are subjected to validation and evaluation by experts.

Data Analysis

The researchers utilized the thorough and reliable data analysis approach developed by Colaizzi (1978). The method consists of seven steps, including reading and rereading the transcript, extracting significant statements that relate to the phenomenon, formulating meanings from meaningful words, grouping those words into theme clusters and themes, developing an exhaustive description of the phenomenon's essential structure or essence, generating a report of the phenomenon's fundamental form, and validating the method. To ensure that the results of the thematic analysis was reliable, manuscript was subjected for debriefer's review.

To ensure the reliability of the thematic analysis, the researchers meticulously prepared an audit trail, documenting each step of the analysis process. This record enhances transparency and allows others to trace the procedures followed. Additionally, the manuscript underwent a thorough debriefer's review, where an

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independent expert critically evaluated the analysis and findings. This review process helped identify potential biases, validate the interpretations, and strengthen the overall credibility of the study.

Ethical Considerations

Each participant in the study and the appropriate authorities were provided with the letters and forms required to successfully complete the research. These letters and forms dwelled on seeking permission from school authorities and participants and informing them of what the study entailed and their rights if they decided to participate. The participants are assured of confidentiality and informed that the study's findings are used for academic purposes only. The participants are not coerced to participate and are informed about the procedures involved in research, and their consent to participate is elicited. All participants are entitled to the right to privacy and dignity of treatment. The research employed all avenues and opportunities to ensure that all issues considered unethical in the context of the study were addressed. Questions to be included are ethically considered to avoid personal sensationalism and sentimentalism.

Results & Discussions

Areas in Urban Farming relevant to Learning Mathematics

Maximizing Yield and Sustainability through Innovative Vertical Farming and Intercropping Techniques

Csordás and Füzesi (2023) stated that in the present dynamic economic and social environment, there is an urgent need for diversified and sustainable agricultural solutions that can effectively increase yields and protect crops. Given the urgency of these challenges, it is crucial to explore new technologies and creative approaches that can solve these problems and facilitate the transition to a greener and more sustainable green economy.

"*In urban agriculture, there is what we call space technology, time technology… urban agriculture is really a farming system forced in a small space*." – Agri. Exp. 1

Kalantari et al. (2018) suggested that implementing strategic crop stand techniques provides farmers with a practical space optimization solution, allowing them to address issues related to microclimate effectively. Additionally, having more space available encourages healthier plant growth and creates an environment that is less susceptible to pests and diseases. This idea is supported by the response of one of the participants.

"*If you can utilize just a 10-square meter area, it's already good enough through vertical farming. You make use of the vertical space instead of just relying on the horizontal space… You need to employ vertical farming techniques to maximize your space*." – Agri. Exp. 2

The participants' responses show that vertical farming is the best urban farming method for practicing sustainable agriculture in urban centers. This claim is also supported by the article from Haus von Eden (2024), which stated that vertical farming is a pioneering idea that enables food to be produced in environmentally friendly and large quantities directly in urban

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centers. In addition, the article by Haus von Eden points out that with vertical farming, vegetables can be grown anywhere in the world in a space-saving manner, regardless of the weather. This should cover the growing demand for food and relieve traditional agriculture.

Mathematics for Home Farming: Learn through Discovery and Practical Engagement

Home farming, a form of urban farming that involves growing crops, vegetables, and fruit in the home garden, allows students to learn math and sustainability. As one participant said:

"*Home farming serves as an early learning platform and emphasizes that learning begins at an early age, beyond school*" – Agri. Exp. 1

Another participant emphasized the importance of integrating urban farming into the curriculum, stating that:

"*urban farms integrated into school curricula provide accessible and valuable opportunities for children to learn about sustainable farming practices, including soil and worms, and go beyond synthetic farming*" – Agri. Exp. 2

Participants also recognized the importance of mathematics in urban farming. As one participant mentioned,

"*There are patterns in polynomials, just like polynomial functions, graphs, right? And problem solving, and for example you can relate it to the sequences, series, patterns. The patterns, their arrangement at urban garden*." – Educ. Exp. 3

This illustrates the connection between mathematics and urban agriculture, where patterns in polynomial functions, graphs, and sequences can be observed in the design of urban gardens. Jain (2022) supports this perspective, stating that mathematics plays a crucial role in agriculture, including soil analysis, fertilizer content calculation, and using statistics in estimates. As noted by participants, math is essential in determining garden area, the percentage of rotten tomatoes, and planning crop quantities to be grown. It is crucial to integrate mathematics into the urban farming curriculum. This prepares students to contribute to sustainable development by providing the necessary mathematical skills.

Furthermore, the inclusion of urban agriculture in education for sustainable development is consistent with the goal of educating students about the conditions of the planet, environmental issues, and strategies to address these challenges. By participating in urban farming, students are not only learning about food shortages but also the environmental challenges they face today.

Competencies that the Project-based Learning Package Should Address

Competency Alignment: Generate Pattern as least-learned

According to Niehoff (2020), competency-based education is a system that focuses on students' demonstration of the knowledge and skills they are expected to learn, and that includes instruction, assessment, grading, and reporting. A participant echoed this definition, explaining:

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"*Competency should align with project timelines, emphasizing the importance of relevant skills within specific time constraints*." – Educ. Exp. 1

Wolfe (2022) states that competencies are skills more easily matched with the work required for project-based learning. This viewpoint supports the premise that skills assist teachers in developing open-ended questions and ability-based learning objectives, thereby improving project authenticity and clarity. Another instructor who took part in the discussion agreed with this.

"*Identifying the least learned competency allows individuals to compensate for struggles with written outputs by demonstrating their abilities through performance tasks*." – Educ. Exp. 3

The need to identify the least learned competency was also emphasized during the interviews. This method compensates for challenges with written findings by proving aptitude through performance activities. This finding is consistent with the notion that competencies allow students to exhibit their abilities using various evaluation techniques (Niehoff, 2020).

In brief, incorporating competence alignment into project-based learning ensures students develop relevant and valuable skills in specific circumstances. Educators can create authentic and practical learning experiences that foster deep understanding and skill development by integrating competencies into classroom design. Identifying and addressing the least learned competencies allows for targeted support and alternative assessments to meet different learning needs. Competency-based education can potentially improve student learning outcomes and prepare people for success in a complex and changing world.

In the context of aligning competencies with project-based learning, one of the participating educators stressed the need for projects to be purposeful and obvious and not just exist for the sake of the project. They emphasized that the outcomes of the learning pack should be informative and relevant so that learners can engage and acquire knowledge through the learning materials. In addition, another participating teacher emphasized the importance of identifying the least learned competencies to facilitate the development of performance tasks within project-based learning packages. By understanding the areas in which students struggle most, teachers can design projects that allow students to demonstrate their skills and overcome any challenges encountered in interpreting documents.

In addition, a participant emphasized the importance of aligning subject progression, Educ. Exp. 3 also emphasizes generating patterns as one of the least learned competencies at Davao City National Secondary School.

"*They can relate it to sequences, series, patterns. The patterns can be related to the urban garden*." – Educ. Exp. 3

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Figure 2 shows the analysis of participants' responses.

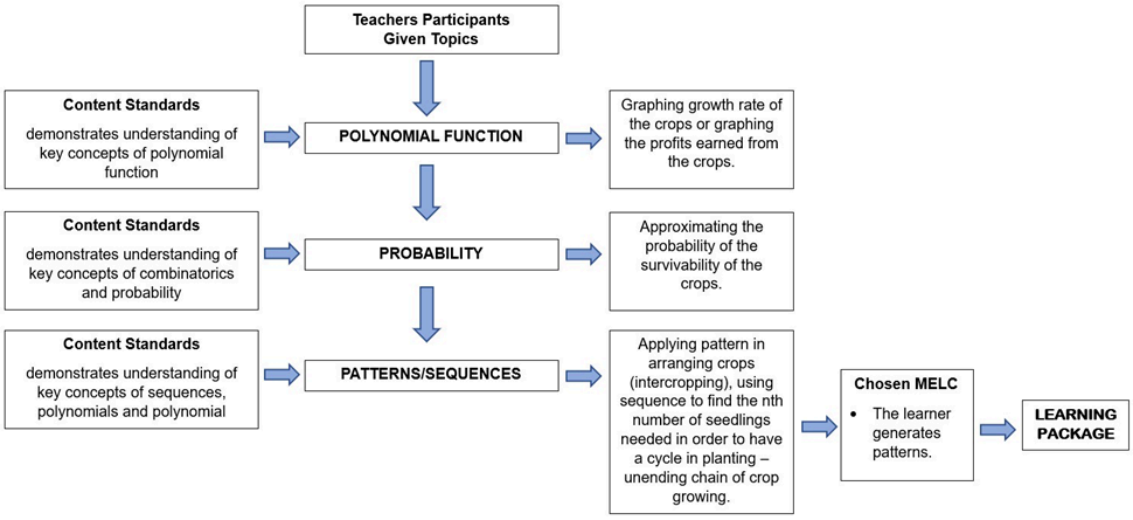

Figure 2. Analysis of Teacher Participants Given Topics

Teaching and Learning Package that can be Proposed

Interactive learning is an educational approach that emphasizes active participation and student engagement. It is crucial to make the learning package interactive, to include tangible elements, and to allow students to achieve tangible results. This concept is supported by Schneider et al. (2011), who found that using concrete interfaces in group activities resulted in better task completion, more significant learning gains, greater exploration of alternative solutions, and greater perceived enjoyment of problem-solving. Participants in the discussion emphasized the importance of interactive learning and tangible results.

"*If it is done properly, if group activities are well-managed, aside from that, it should be output-based, not just theoretical. They should not just solve problems; there should be tangible outputs*." – Educ. Exp. 3

Stressing the need for well-organized group activities and tangible results, one participant explained that the learning pack should be broader than theoretical concepts or problem-solving exercises. They stressed the importance of incorporating physical assets and products into the learning experience.

The same participant added ideas, stressing the importance of an interactive approach with tangible results that students can apply.

"*It should be presented in an interactive way that can be applied by the children and has tangible outputs. It should be interactive and manipulative*." – Educ. Exp. 3

They emphasized the value of interactive and manipulative activities to promote engagement and learning. These statements by the research participants are consistent with the findings of

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Schneider et al. (2011) and point out that interactive learning experiences with tangible interfaces promote effective group work, the exploration of alternative solutions, and a positive perception of problem-solving.

Including interactive and tangible elements in the learning package increases student engagement, encourages active participation, and supports meaningful learning. Using concrete interfaces and including concrete outcomes contribute to more effective group activities, greater exploration of solutions, and a more enjoyable problem-solving experience for students (Schneider et al., 2011).

The above themes imply that maximizing yield and sustainability through innovative vertical and intercropping techniques, math for home farming, competency alignment, and interactive learning opens up exciting opportunities to enhance the educational experience.

Students embark on a journey of discovery and explore the world of agriculture and sustainability. Students can immerse themselves in vertical farming and learn about advanced techniques that maximize crop yields and minimize environmental impact. Through intercropping, they discover the power of growing different crops together and understand how each plant benefits the other, creating a more sustainable and efficient ecosystem. Nevertheless, it does not stop there. Mathematics takes center stage as students explore the practical application of mathematical concepts in local farming. They measure the area of their garden plots, calculate the proportion of ripe fruit or vegetables, and use mathematical reasoning to plan and optimize the production of their crops. This interdisciplinary approach bridges the gap between theory and practice and helps students see the relevance of mathematics in their everyday lives.

On the other hand, competency alignment becomes a guiding principle in the learning package. Teachers identify the areas where students struggle the most and design specific activities and projects to address those weaknesses. In this way, they allow students to demonstrate their skills through performance tasks and offset any challenges they may face in written results. In order to make the learning experience even more appealing, the focus is also on interactive learning strategies. Students actively engage, manipulate tangible interfaces, and participate in hands-on activities. Excitement reigns in the classroom as the connections between agricultural patterns and mathematical concepts such as polynomials, graphs, sequences, and patterns are explored. Through interactive learning, students take ownership of their education, encouraging a deeper understanding and retention of the subject.

In this interactive educational environment, students learn the principles of agriculture and sustainability and develop essential skills for success. Students will become influential critical thinkers, problem solvers, and communicators and have the skills to tackle real-world challenges. Figure 3 depicts the design and development of the project-based learning package.

The study confirms previous research that highlights the benefits of PjBL in enhancing student engagement, critical thinking, and problem-solving skills in mathematics. Chen and Yang (2019) found that PjBL fosters academic achievement by immersing students in complex, real-world problems, a result echoed in this study. By integrating mathematics with agricultural practices, such as optimizing vertical farming space and calculating intercropping arrangements, students engaged in hands-on tasks that directly connect mathematical theory to practical application. This is consistent with the findings of Laurens et al. (2017), who emphasized the importance of contextualized learning in improving mathematical cognitive achievement.

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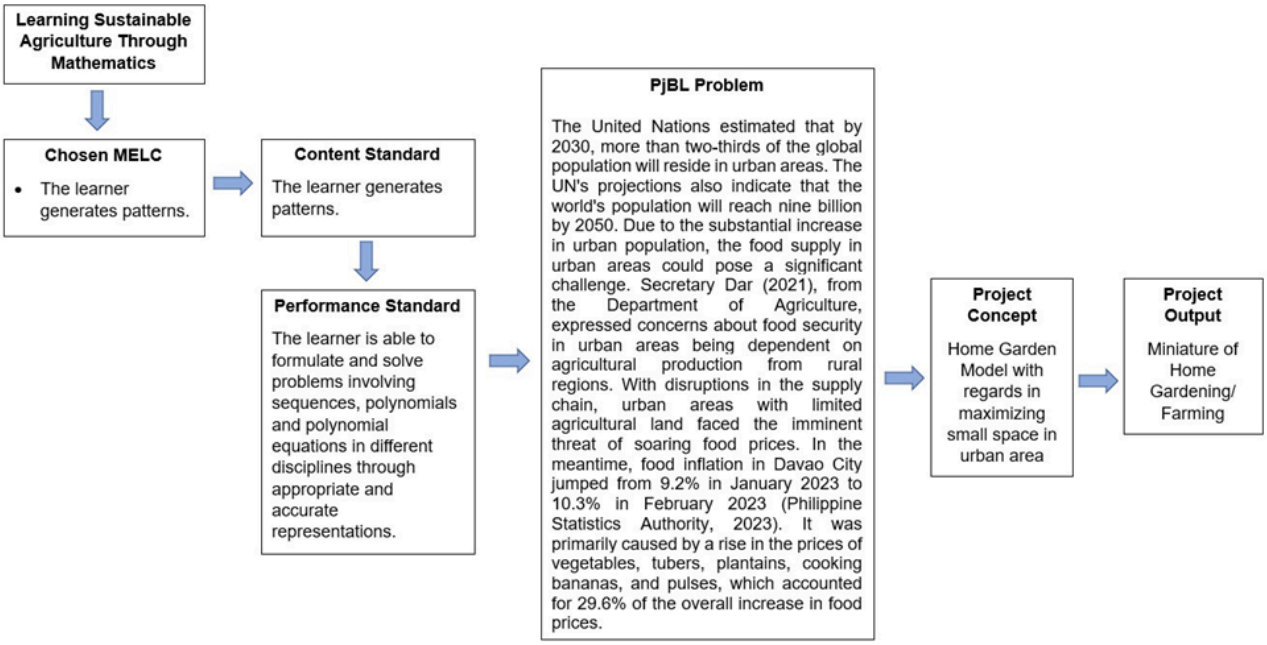
Additionally, the study supports the idea that PjBL can cultivate essential 21st-century skills, as noted by Siswono et al. (2018). Through collaboration and interactive problem-solving within agricultural projects, students demonstrated improved communication, creativity, and teamwork, reinforcing the value of interdisciplinary approaches in education.

The study contributes a unique perspective by demonstrating how sustainable agriculture can serve as a thematic anchor for PjBL in mathematics education. This interdisciplinary approach bridges existing gaps in the literature, particularly the lack of studies exploring the intersection of mathematics, agriculture, and sustainability. It highlights the potential of PjBL to not only enhance mathematical understanding but also foster environmental awareness and sustainable practices among students, aligning with global education goals for sustainability. Furthermore, the study identified a distinct emphasis on addressing least-learned competencies, such as generating patterns, which has not been a primary focus in earlier PjBL research. This targeted approach ensured that the learning package was not only interdisciplinary but also specifically designed to address critical gaps in student understanding.

Figure 3. Designing of Project-Based Learning Package



Conclusion

Home farming, as a form of sustainable agriculture, presents a unique opportunity to integrate mathematical concepts into real-world contexts, thereby enhancing students' mathematical competencies. By applying the principles of home farming to mathematical

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learning, researchers have developed a project-based learning package aimed at addressing and improving identified least learned competencies in grade 10 mathematics. This learning package goes beyond traditional classroom instruction by incorporating interactive learning activities, hands-on manipulation of mathematical concepts, and practical applications in the context of home farming. Through engaging with these features, students not only deepen their understanding of mathematical concepts but also develop critical thinking skills, problem-solving abilities, and a greater appreciation for the relevance of mathematics in everyday life.

Future research should focus on testing the effectiveness of the developed learning package in diverse educational settings. Specifically, experimental studies could assess its impact on students' academic performance, engagement, and 21st-century skill development. Additionally, researchers could explore the package's adaptability to other agricultural contexts, such as aquaponics, agroforestry, or hydroponics, to determine its applicability across varied environments and agricultural systems. Longitudinal studies could also evaluate how integrating sustainable agriculture into mathematics education influences students' long-term attitudes and behaviors toward sustainability. Finally, collaboration with agricultural experts and educators from different regions may help refine and expand the learning package to address localized agricultural practices and challenges, further enhancing its versatility and relevance.

It is suggested that researchers consider exploring diverse agricultural concepts beyond urban or home farming, identifying new contexts where mathematical concepts can be applied. Additionally, for educators, integrating sustainable agriculture into mathematics instruction is recommended, providing students with practical, real-world applications that deepen their understanding of mathematical concepts. Furthermore, agricultural experts are urged to collaborate with school administrators to share their knowledge and expertise with students, enhancing their understanding of agriculture and contributing to achieving the 17 Sustainable Development Goals. Through such collaborations, students can gain valuable insights into sustainable agricultural practices while fostering a sense of responsibility toward global sustainability efforts.

Patents

Supplementary Materials: The Project-Based Learning Package can be downloaded at: https://drive.google.com/file/d/1L-TrGPfCAgEPYanFGchlw5zl4H-ivYUU/view?usp=sharing

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