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Precision Agriculture Ecosystem Innovation through IoT Technology: A Study of Learning Factory Development for Farmer Empowerment in Ngajum Village

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ABSTRAK

Pertanian presisi merupakan pendekatan inovatif yang mengintegrasikan teknologi digital guna meningkatkan efisiensi dan produktivitas sektor pertanian. Penelitian ini bertujuan untuk mengembangkan ekosistem pertanian presisi melalui implementasi Smart Agriculture Greenhouse berbasis Internet of Things (IoT) sebagai model learning factory dalam mendukung kemandirian petani di Desa Ngajum. Pendekatan penelitian yang digunakan adalah kualitatif deskriptif, dengan teknik pengumpulan data berupa studi lapangan, observasi, serta wawancara mendalam yang melibatkan petani, pendamping, dan pemangku kepentingan lokal. Hasil penelitian menunjukkan bahwa penerapan teknologi IoT pada smart greenhouse memungkinkan pemantauan dan pengendalian kondisi lingkungan pertanian secara real-time, sehingga meningkatkan akurasi pengambilan keputusan dalam proses budidaya. Selain itu, konsep learning factory berperan sebagai media pembelajaran kontekstual yang efektif bagi petani dalam menguasai keterampilan pertanian modern secara aplikatif. Implementasi program ini juga mendorong terjadinya perubahan paradigma petani dari praktik pertanian konvensional menuju pendekatan yang berbasis data dan teknologi. Ekosistem yang dikembangkan berfungsi sebagai pusat edukasi, produksi, dan inovasi pertanian berkelanjutan di tingkat desa. Temuan penelitian ini mengindikasikan bahwa sinergi antara teknologi, pendidikan, dan pemberdayaan masyarakat mampu menghasilkan model pertanian cerdas yang adaptif serta berpotensi untuk direplikasi dalam mendukung kemandirian pangan lokal. Dengan demikian, pengembangan ekosistem pertanian presisi ini dapat menjadi referensi dalam upaya transformasi sektor pertanian di wilayah perdesaan lainnya.

ABSTRACT

Precision agriculture is an innovative approach that integrates digital technology to improve the efficiency and productivity of the agricultural sector. This study aims to develop a precision agriculture ecosystem through the implementation of a Smart Agriculture Greenhouse based on the Internet of Things (IoT) as a learning factory model for fostering farmer independence in Ngajum Village. The methods used include a qualitative-descriptive approach with field studies, observations, and in-depth interviews with farmers, assistants, and local stakeholders. The results of the development show that the use of IoT technology in smart greenhouses allows real-time monitoring and control of the agricultural environment, thereby increasing the accuracy of decision-making in cultivation. In addition, the learning factory concept can be a contextual learning medium for farmers to master modern agricultural skills practically. This program also encourages the transformation of farmers' mindsets from conventional practices to data-based and technology-based practices. The ecosystem that is formed acts as a center for education, production, and sustainable agricultural innovation at the village level. These findings show that collaboration between technology, education, and community empowerment can create an adaptive and replicable smart agriculture model to support local food independence. The development of an ecosystem like this has the potential to be a reference in agricultural transformation in other rural areas.

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1. INTODUCTION

An innovative strategy to address the challenges of farmer productivity and independence in the digital era is to build a precision agriculture ecosystem using Greenhouse Smart Agriculture based on the Internet of Things (IoT). This initiative aims to create an educational factory in Ngajum Village. This factory will function as a center for modern agricultural production and also offer farmers training and education on technology-based agrarian skills. The development of Internet of Things (IoT) technology, including smart sensors, devices, network topologies, big data analytics, and intelligent decision-making, is seen as a solution to automate various parameters in greenhouse farming, such as internal atmosphere control, irrigation regulation, plant growth monitoring, and so on (Jahirul et al., 2022). This method helps farmers understand the concept of precision agriculture that combines Internet of Things sensors, data-based monitoring systems, automatic temperature and humidity regulation, and real-time plant nutrient management. As a result, farming can be carried out more efficiently, productively, and sustainably.

Schools, village governments, and technology partners work together to build this ecosystem, which is a local agribusiness development model that can be applied elsewhere. Smart greenhouses are designed to increase agricultural yields and provide farmers with knowledge about the importance of digital transformation in agriculture. Farmers have the opportunity to learn, try, and apply technology independently in the cultivation process through a hands-on, experience-based learning system. The integration of IoT, artificial intelligence (AI), and web services in agriculture increases efficiency, productivity, and sustainability (AlZubi & Galyna, 2023). This program is expected to be able to create new farmers who are adaptive to technology and strengthen local food security. In addition, the integration of the learning factory approach makes this ecosystem a living lab that combines applied research, community empowerment, and sustainable agricultural business development. With the support of this ecosystem, Ngajum Village has great potential to become a pilot village based on highly competitive smart farming. This device allows real-time monitoring, data-based decision-making, and automation, which ultimately increases productivity and sustainability (Javaid et al., 2022). The development of a precision agriculture ecosystem using the Internet of Things (IoT)-based Smart Agriculture Greenhouse shows a significant transformation in the world of modern agriculture, especially in facing the challenges of productivity, resource efficiency, and climate change. Precision agriculture technology is present as a solution to optimize the cultivation process through a data-driven and automated approach. IoT-based smart greenhouse models and simulations have been explored to achieve more sustainable agriculture and reduce energy consumption (Kouadria et al., 2025). Smart greenhouses enable digital and real-time management of plant growing environments, relying on sensors and IoT devices to monitor and regulate important variables such as temperature, humidity, light, and plant nutrients.

The development of a precision agriculture ecosystem using a Smart Agriculture Greenhouse based on the Internet of Things (IoT) shows a significant transformation in the world of modern agriculture, especially in facing the challenges of productivity, resource efficiency, and climate change. Precision agriculture technology is present as a solution to optimize the cultivation process through a data-based and automated approach. IoT-based smart greenhouse models and simulations have been explored to achieve more sustainable agriculture and reduce energy consumption (Kouadria et al., 2025). Smart greenhouses enable digital and real-time management of plant growing environments, relying on sensors and IoT devices to monitor and regulate important variables such as temperature, humidity, light, and plant nutrients. This encourages agriculture to be more precise, adaptive, and sustainable. This ecosystem continues to develop through cross-sector collaboration, ranging from educational institutions, farming communities, and governments to technology industry players. The implementation of smart greenhouses is not only focused on increasing crop yields but also on building the capacity of agricultural and human resources through integrated learning systems such as learning factories, which make farmers active subjects in mastering technology. In various regions, including agricultural villages such as Ngajum Village, this approach has begun to be adopted to encourage the regeneration of technology-literate and highly competitive farmers. Collaboration platforms, government support, and cross-industry collaboration are essential for a future where smart agriculture meets the needs of sustainable food production (Muthukumar & Karthick, 2025).

Modern agricultural skills based on Internet of Things (IoT) technology are becoming an increasingly important need for farmers in the era of digital transformation, including for farmers in Ngajum Village. Amid the challenges of climate change, fluctuating commodity prices, and limited land and labor, conventional agriculture is no longer sufficient to ensure the sustainability of production and the welfare of farmers. IoT-based training can increase agricultural efficiency and productivity. A case study in Chiang Mai shows that training using the Kirkpatrick model shows an increase in farmer knowledge and performance (Chernbumroong et al., 2022). Therefore, mastering modern agricultural skills is key for farmers to be able to adapt, increase productivity, and manage their farming businesses more efficiently and based on data.

In Ngajum Village, this skill improvement is not only to encourage the modernization of the agricultural sector but also to create long-term farmer independence. Training and mentoring programs accompanied by the implementation of a smart agriculture-based learning factory are strategic steps to build the capacity of local farmers. With these skills, farmers are expected to not only become implementers but also innovators who are able to develop technology-based agricultural solutions independently. The importance of modern IoT-based agricultural skills lies in their role in strengthening food security, increasing production efficiency, and making farmers the main actors in a smart and sustainable future agricultural ecosystem.

2. LITERATURE REVIEW

Precision Agriculture and Digital Transformation in the Agricultural Sector

A technology-based approach known as precision agriculture leverages data and digital systems to improve agricultural productivity, efficiency, and sustainability. Precision agriculture enables the use of sensors, GPS, drones, and cloud-based data processing to manage land and crops specifically according to local needs. Precision agriculture is important in the Industrial Revolution 4.0 era to overcome traditional agricultural challenges such as dependence on manual methods, resource constraints, and climate change. Using IoT data analytics in the agricultural sector will provide new benefits to increase the quantity and quality of production from agricultural land to meet the increasing demand for food (Akhter & Sofi, 2022).

Along with the development of digital technology and the need for efficient food production, precision agriculture is starting to get attention in Indonesia. Villages like Ngajum have great potential to implement this method because of the support of the agrarian ecosystem and the community's heavy dependence on agriculture. The adoption of precision agriculture affects productivity and creates innovations and mindsets that are data-driven. Other studies highlight the tangible benefits of these technologies through real-world case studies and evaluate their effectiveness in improving emissions monitoring, operational efficiency, and environmental compliance (Ahmed & Shakoor, 2025).

IoT-Based Smart Greenhouse as a Learning Factory for Farmer Capacity Building

One example of precision agriculture technology is a smart green greenhouse built using the Internet of Things (IoT). This greenhouse is equipped with sensors and actuators that automatically monitor and regulate environmental conditions such as temperature, humidity, light intensity, and irrigation. The use of IoT sensors in the greenhouse allows for real-time monitoring and adjustment of environmental conditions to support optimal plant growth (Al-Qudah et al., 2025).

A practice-based training and education method, the learning factory approach, is very effective in improving the capabilities of agricultural human resources. This concept was originally used in the manufacturing industry but is now widely used in vocational education, including agriculture. In a learning factory, participants not only gain theoretical understanding but are also able to apply technology in the agricultural process directly. This model is used in Ngajum Village as a strategic means to introduce Internet of Things (IoT)-based agricultural technology to farmers systematically, practically, and oriented towards independence..

3. RESEARCH METHOD

The implementation of the program to address partner problems will be carried out through several structured stages. Each stage is designed to involve partners actively, ensure program sustainability, and provide maximum impact.

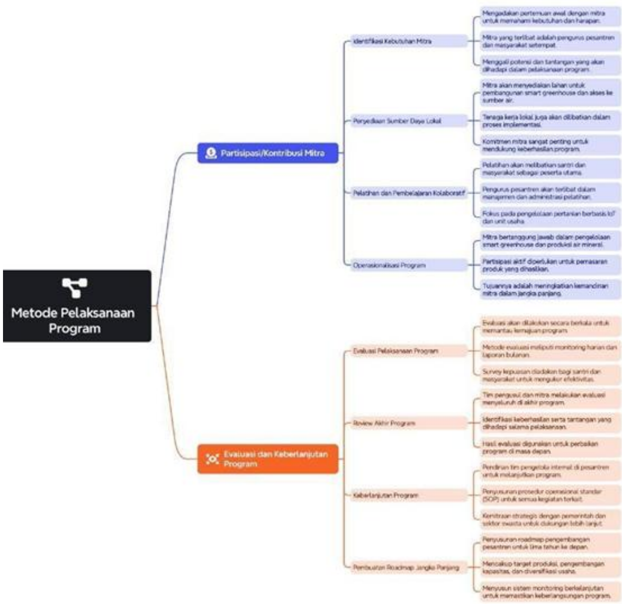

Figure 1. Implementation Method

a) Partner Participation/Contribution

1. **Identification of Partner Needs:** The first stage is an initial meeting with partners to explore specific needs. Partners, in this case, the Ngajum village government and the community, will provide input regarding existing potential, challenges faced, and their expectations for this program.
2. **Provision of Local Resources:** Partners will contribute by providing relevant resources, such as land for smart greenhouse construction, access to water sources,

and local labor. This participation demonstrates the partner's commitment to supporting program implementation.

3. **Collaborative Training and Learning:** Partners will be involved in training and mentoring, both in IoT-based agricultural management and business unit management. Students and the community will be the main participants in the training, while village administrators will be involved in management and administration.
4. **Program Operationalization:** Partners will take an active role in running the program, such as smart greenhouse management, mineral water production, and product marketing. This participation aims to increase partner independence in the long term.

b) Program Evaluation and Sustainability

Program Implementation Evaluation

Evaluation is conducted periodically to ensure that the program is running according to plan. Evaluation methods include:

1. **Daily Monitoring:** Daily activities in smart greenhouse construction, training, and resource management will be monitored by the proposing team and partners.
2. **Monthly Report:** Partners will prepare monthly reports on program progress, including production data, income, and the number of participants involved.
3. **Satisfaction Survey:** Surveys are conducted with students and the community to measure the effectiveness of training and the level of satisfaction with the program.
4. **End of Program Review:** The proposing team and partners will conduct a comprehensive evaluation at the end of the program to identify successes and challenges faced.
5. **Program Sustainability** : To ensure the sustainability of the program after the community service activities are completed, the following steps will be taken:
6. **Establishment of the Management Team:** An internal management team is formed in the village consisting of administrators, students, and the local community to continue the program.
7. **Preparation of SOP:** Standard operating procedures (SOP) are prepared for the operation of smart greenhouses, mineral water production, and other empowerment activities. Strategic Partnerships: Partners will be directed to establish partnerships with the government, educational institutions, and the private sector to obtain additional funding or technical support.
8. **Long-Term Roadmap Development:** A five-year village development roadmap will be developed, including production targets, capacity development, and business diversification.
9. **Continuous Monitoring System:** Villages will be guided to implement a simple but effective monitoring system to ensure the program is running according to plan.

4. RESULT AND DISCUSSION

This community service was carried out in two stages, which are explained as follows:

1. Preliminary Study

Needs analysis for the development of "Precision Agriculture Ecosystem using IoT-Based Smart Agriculture Greenhouse as a Learning Factory for Fostering Independence for Students Related to Modern Agricultural Skills with a Matching Fund Scheme with Ponpes Sirajut Thilibin Ngajum" is very important to design the right program to improve the skills of students and their independence in the field of modern agriculture. The results of the initial study showed that Ponpes Sirajut Thilibin Ngajum faced a number of problems in the advancement of contemporary agricultural technology, such as a lack of understanding of appropriate farm technology and limited access to relevant technological devices. In addition, students received less practical training on the use of IoT-based agricultural systems. In addition, there is a lack of funds to build infrastructure that supports contemporary agrarian systems.

An effort to overcome this problem is to build an Internet of Things-based Greenhouse Smart Agriculture system that is integrated with automation technology for monitoring and managing agriculture. This system will allow teachers to learn firsthand about modern technologies in crop cultivation, such as temperature and humidity monitoring and automated irrigation control. In addition, it is essential for students to be technically trained to use IoT technology and the application of precision agriculture. Funding for the necessary training, purchase of IoT devices, and infrastructure development will be made possible through a matching fund scheme. To ensure smooth implementation, the role of Ponpes Sirajut Thilibin as a mediator and liaison between technology providers and students is essential. Students will have modern agricultural skills that can increase their independence and competitiveness in the farming sector, both locally and nationally, with the support of appropriate technology and education.

Table 1. Analysis of the Need for Learning Media related to IoT-based smart agriculture greenhouses as learning factories for students

NO	QUESTION	ANSWER OPTIONS	PERCENTAGE
1	Have you ever used digital learning media (videos, simulations, applications)?	Ever	35%
		Never	65%
2	What learning media do you like the most to learn modern agriculture?	Learning Videos	35%
		Printed Modules	40%
		Interactive Simulations	15%
		Direct Practice	10%
3	Have you ever learned about precision agriculture or IoT technology in agriculture?	Yes	25%
		No	75%
4	How useful is technology-based media in helping you understand modern agriculture?	Very useful	55%
		Quite useful	30%
		Less useful	10%
		Don't know	5%
5	Does the village provide facilities for learning current agricultural practices?	Every day	10%
		Every week	30%

		Every month	40%
		Rarely	20%
6	Do you have access to digital devices (cellphones, laptops, tablets) for learning?	Yes, Personal	60%
		Yes, Borrowed	30%
		None	10%
7	Have you ever used IoT-based applications or automatic crop monitoring technology?	Yes	25%
		Never	65%
		Have Seen but Not Tried	10%
8	Do you feel the need for training to use Smart Greenhouse-based agricultural technology?	Very Necessary	50%
		Necessary	45%
		Not Necessary	5%
9	How interested are you in learning modern technology-based agriculture?	Very Interested	60%
		Quite Interested	30%
		So-so	10%
		Not Interested	0%
10	In your opinion, will the use of technology-based learning media increase the economic independence of students?	Yes	70%
		No	5%
		Don't Know	25%

Based on Table 1. the results of the analysis of learning media needs in Ngajum village show that although technology in contemporary agricultural learning is still very limited, there is great potential for development. The increasing use of digital technology and AI has a major impact on agriculture as an industry and market, affecting people who work and have an interest in agriculture as well as the agricultural community (Bampasidou et al., 2024). Only 35% of respondents have ever used digital learning media such as simulations, videos, and learning applications, according to the data. This shows that technological interventions in the village environment are not evenly distributed. As many as 60% of students expressed great interest in technology-based learning, and 55% admitted that technology-based media were very helpful in understanding agricultural material properly. However, 80% of students have never received learning directly related to the Internet of Things technology in agriculture, which shows that there is a gap between the learning content currently available and future skill needs. Direct practice and interactive simulations are the most popular learning media, with a percentage of 35%, followed by learning videos and 30%. This shows that teachers are more receptive to participatory and visual learning approaches than printed materials. Interestingly, 70% of respondents said that technology learning media can increase economic independence, which shows that there is an awareness of the benefits of technology in agriculture. The integration of digital technology, such as interactive videos and IoT-based simulations, can increase students' motivation and understanding in the field of agriculture (Thiagarajah et al., 2024). Thus, the results of this analysis are an important basis for designing contextual, applicable learning media that can bridge the transformation of students' skills towards digital technology-based precision agriculture. In general, the use of digital agriculture can maximize results according to the needs and conditions of students (Chaichana et al., 2024).

2. Curriculum Development and Learning Materials

This program uses a learning factory learning approach, a hands-on, practice-based education model that involves students as active actors in the process of producing knowledge and skills. The Factory of Learning combines theory, practice, and contemporary technology in an integrated and contextual learning ecosystem. In situations like this, an Internet of Things (IoT)-based greenhouse is the main source of learning. IoT allows students to carry out various appropriate agricultural processes, such as processing planting media, digitally monitoring plant conditions, and making decisions based on environmental data.

The principle of experiential learning or learning based on real experiences is the basis of this learning model. By using technology, students will be actively involved in farming activities and still receive guidance through digital modules, simulations, and collaborative discussions. By using Internet of Things technology, the learning process becomes more flexible and responsive to environmental changes. In addition, it teaches 21st-century skills such as problem-solving, critical thinking, and digital literacy. The ultimate goal of this program is to create students who are financially independent and ready to become actors in the modern agricultural sector. Therefore, strengthening the values of independence and entrepreneurship is an important part of learning. This method not only improves the quality of learning but also forms a sustainable learning culture in the village. This is in line with the spirit of village-based vocational education transformation, which combines spiritual values, technical skills, and work readiness in one educational process..

Figure 2. Design of Learning Materials and Media Related to Introduction to Precision Agriculture and the Smart Greenhouse Concept

Based on Figure 2, in this module, students will be introduced to the concept of precision agriculture as a farming method that utilizes data and digital technology to increase production efficiency, reduce waste, and maintain environmental sustainability. They will also understand how smart plantations are one example of the application of precision technology in agriculture. This module is designed using an exploratory and contextual approach; this module combines inspiring stories about the difficulties of traditional farmers with the opportunities of modern technology to address the food crisis and climate change. To improve students' critical thinking, the main media in the form of infographics, short documentary videos, and light group discussions are used. The goal is to increase initial awareness and desire to learn and emphasize how important it is for the younger generation to participate in future agriculture.

Figure 3. Design of Learning Materials and Media Related to the Use of IoT Sensors for Plant Monitoring in Greenhouses

Based on Figure 3, students will learn more about precision agriculture techniques in this module, especially how to use Internet of Things (IoT) sensors to manage the plant environment in a greenhouse. They will learn about various types of sensors, including those that measure temperature, humidity, pH, and water nutrients, and how data from these sensors is sent and processed through a digital system. They will also learn to operate an IIoT-based monitoring system through simulations and hands-on practice. The concept of problem-solving-based practice also known as problem-based learning is used in this module. Simple case studies such as "How to maintain ideal humidity for lettuce plants in a greenhouse during the dry season" will be presented to students. The use of instructional videos, the use of simple sensor devices, and simulations of dashboard monitoring applications are all methods used to provide instruction. These methods aim to improve students' technical skills and analytical thinking logic while increasing their digital knowledge of contemporary agriculture.

3. Platform Development

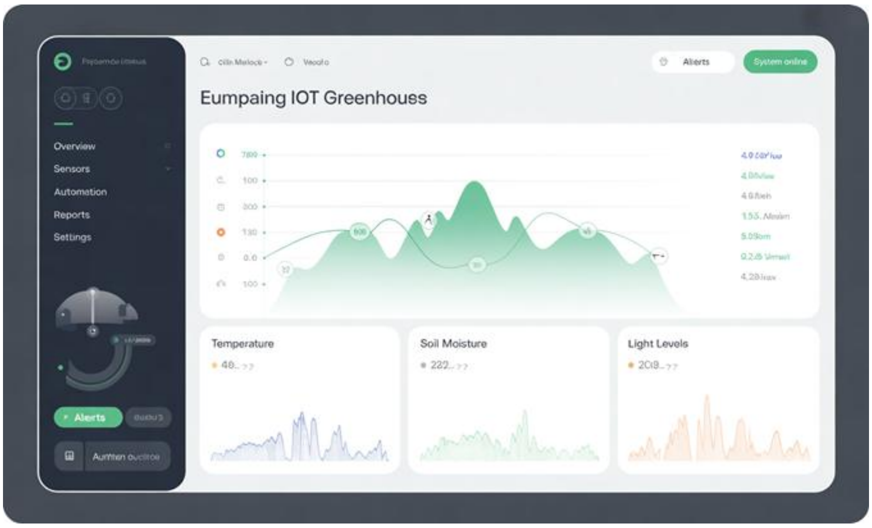

Figure 4. IoT Greenhouse Monitoring Dashboard

Based on Figure 4, this feature is the main control center for students to monitor plant conditions in the greenhouse in real time. The dashboard is integrated with various IoT sensors that record environmental data such as temperature, humidity, light intensity, and water and nutrient content in the soil or planting media. This information is presented in an easy-to-understand visual form, such as dynamic graphs and color indicators. Through this feature, students can learn to read data, understand plant responses to the environment, and make decisions based on precision agriculture data analysis. Thus, this dashboard is not only a control tool but also an educational media based on data literacy.

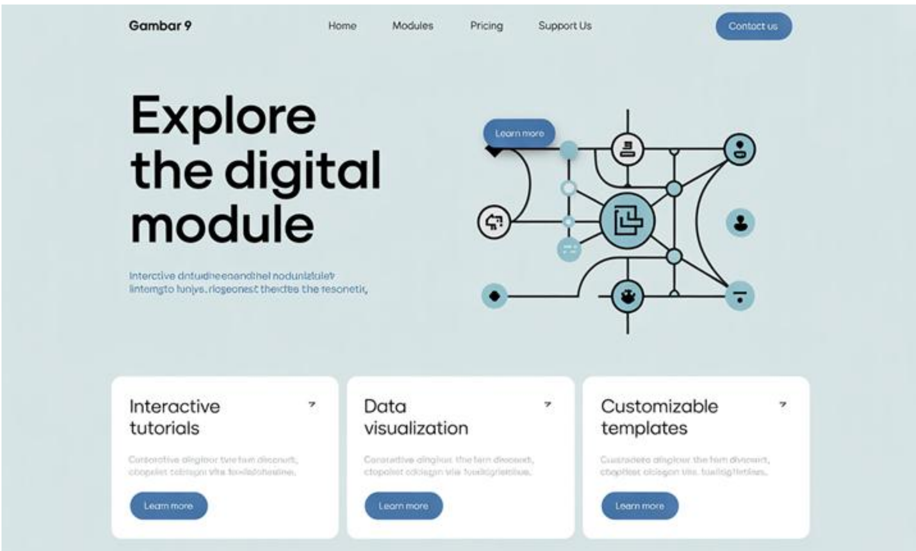

Figure 5. Interactive Digital Module

Based on Figure 5, this feature provides modern agricultural learning materials that are packaged digitally and interactively. Each module presents a specific theme, such as hydroponic systems, greenhouse management, and introduction to IoT technology, equipped with supporting media such as video tutorials, infographics, interactive quizzes, and case study exercises. The preparation of materials based on the village contextual curriculum makes learning relevant to the needs of students. This module facilitates independent, flexible, and fun learning, which supports the reinforcement of theoretical knowledge before field practice. The interactivity of the module also allows students to get direct feedback on their understanding.

Figure 6. Smart Greenhouse Virtual Simulation

Based on Figure 6, this feature presents a virtual practical experience for students to manage a greenhouse digitally. In this simulation, students can try various scenarios, such as adjusting temperature and humidity or turning on an automatic irrigation system based on virtual sensor data. This feature is designed to resemble real conditions with a game-based learning approach so that it is interesting and interactive and can increase learning engagement. This simulation serves as an important bridge between theory and practice, preparing students to be more ready when practicing directly in a physical greenhouse while also fostering critical thinking and problem-solving skills.

Figure 7. Farmer Discussion and Collaboration Forum

Based on Figure 7, this feature provides a digital interaction space between students and between students and mentors. This forum allows discussions on certain topics, sharing practical experiences, and asking questions about technical problems they face. With a learning community approach, this feature strengthens a collaborative ecosystem that fosters a spirit of cooperation, sharing knowledge, and building networks between villages. Students can also upload documentation of their agricultural activities, such as photos of the planting process, videos of the harvest, or innovation ideas. Through this forum, learning is not only individual but also social, strengthening the culture of collective learning in the village environment.

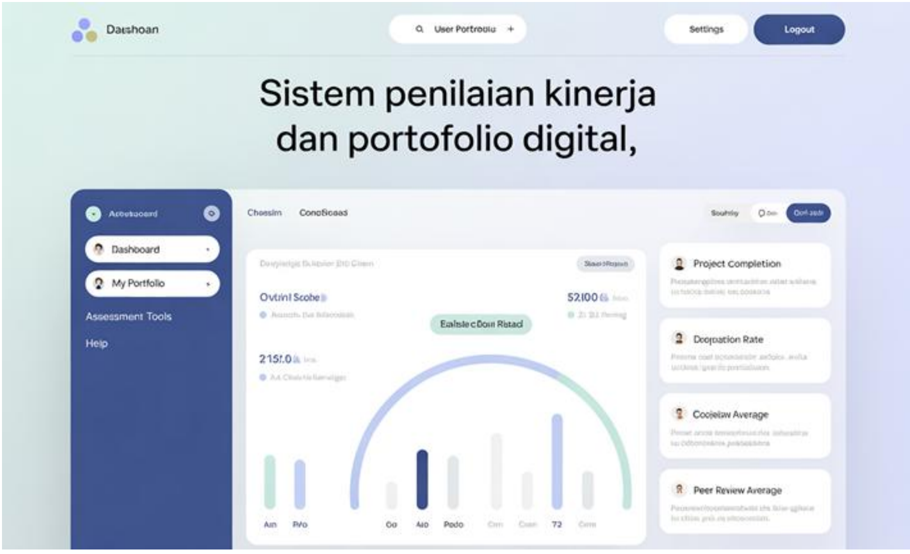

Figure 8. Performance Assessment System and Digital Portfolio

Based on Figure 8, this feature documents the entire learning process and practice of students in digital form. Each student will have an account that records quiz results, module progress, practical activity reports, and the harvests they manage. All of these records will form a digital portfolio that can be used as proof of competence. Assessment is not only based on theory but also based on real performance in the field. This portfolio is very useful for students to demonstrate their capabilities when continuing their studies, opening their agricultural businesses, or getting involved in partnership programs. This feature supports a holistic and future-oriented vocational learning approach.

Figure 9. Integration of Economic Independence and Entrepreneurship Curriculum for farmers

Based on Figure 9, this feature connects technical agricultural learning with strengthening the economic independence of students. The materials provided include agricultural marketing training, product packaging, simple branding strategies, and how to access digital markets. Students will also learn to create small business plans based on their agricultural products. This feature strengthens the village's position as an empowerment institution by producing entrepreneurs who are not only skilled in farming but also have an entrepreneurial spirit. This curriculum integration ensures that precision farming is not only a technical skill but also a sustainable economic provision for students.

4. **Material Validation Test**

The material validation test was conducted as an important step in ensuring the feasibility and quality of the learning content developed in the program "Development of Precision Agricultural Ecosystems Using IoT-Based Smart Agriculture Greenhouses as a Learning Factory for Fostering Independence for Students." The purpose of this validation test is to assess the extent to which the material has met the standards of targeted content, met learning needs, and supported the development of students' skills in agriculture. Three expert validators from the fields of vocational education, agricultural technology, and village curriculum conducted the assessment. Each assessment indicator is represented by a questionnaire with a Likert scale from "very inappropriate" (1) to "very appropriate" (5). The following are the results of the material validation test based on the assessments of the three validators:

Table 2. Learning material test assessment data

No	Selected Criteria	Validator 1 Value	Validator 2 Value	Validator 3 Value	Total	Percentage	Evaluation Criteria
1	Suitability of the material with learning objectives	4	5	4	13	86.7	Good
2	Relevance of the content of the material to the needs of students	5	4	5	14	93,3	Excellent
3	Updating the content of the material	4	4	4	12	80,0	Enough
4	Depth of material	5	5	5	15	100,0	Excellent
5	The truth of the scientific concept	3	4	4	11	73,3	Enough
6	Integration between sub-subjects	4	5	5	14	93,3	Excellent

7	Clarity of material description	4	4	5	13	86,7	Good
8	Language compatibility with the level of understanding of students	5	5	4	14	93,3	Excellent
9	Proper use of terms	5	4	5	14	93,3	Excellent
10	Completeness of supporting media (images, graphics, etc.)	4	4	4	12	80,0	Enough
11	Suitability of the material with the principles of active learning	5	4	5	14	93,3	Excellent
12	Use of real/contextual examples	5	5	5	15	100,0	Excellent
13	Consistency of presentation style	4	4	5	13	86,7	Good
14	Clarity of illustrations or visualizations	4	4	4	12	80,0	Enough
15	Emphasis on character/independence values	5	4	5	14	93,3	Excellent
16	Integration of technology in the material	5	5	5	15	100,0	Excellent
17	Potential to drive digital literacy	4	4	4	12	80,0	Enough
18	Compatibility with the village curriculum	4	5	4	13	86,7	Good
19	Ease of understanding independently	5	4	5	14	93,3	Excellent
20	Potential to develop student entrepreneurship	5	5	5	15	100,0	Excellent
Average						95,6	Excellent

Based on Table 2, three expert validators from the fields of agriculture, vocational education, and village community empowerment conducted a validation test process for learning materials. This validation assessed 20 important indicators related to the quality of content, relevance, and suitability of the material to the context of student learning in the village. The assessment results showed that most of the materials met the eligibility criteria with a high average percentage. Of the 20 indicators evaluated, 12 of them were categorized as "Very Good". These indicators include the depth of the material, the use of real or contextual examples, the integration of technology in the material, and the potential to develop student entrepreneurship. All of these indicators received a perfect score of one hundred percent. This shows that the learning materials are truly intended to demonstrate appropriate and practical agricultural practices. Overcoming this challenge requires a major and rapid transformation in agricultural operations, with an emphasis on innovative and appropriate materials (Densu, 2018). Compliance with the principles of active learning, indicators of the use of appropriate terms, and an emphasis on character values and independence are other advantages, each with a percentage of more than 93%. However, five indicators remain in the "Sufficient" category: up-to-date content (80 percent), correctness of scientific concepts (73.3%), completeness of supporting media, clarity of visualization, and the possibility of increasing digital literacy. This indicates that several aspects need to be updated and supplemented, especially in terms of visual content, idea generation, and the addition of the latest information on Internet of Things-based agricultural technology.

Overall, the validation results show that the learning materials have very good quality and are suitable for use in teaching students in villages that use contemporary agricultural technology. In agricultural education, facilities and equipment are very important because they provide students with the opportunity to learn based on experience and use various learning styles (Zarafshani et al., 2020).

5. Learning Media Validation Test

The learning media validation test was carried out as an important part of the process of developing a technology-based learning system for students in villages. The media developed in this program include interactive videos, infographics, IoT-based simulations, and digital guides that support the learning process about precision agriculture in smart greenhouses. This validation aims to ensure that the media used is not only visually appealing but also effective in conveying information and supporting students' understanding of concepts. The following are the results of the material validation test based on the assessment of the three validators:

Table 3. Learning media test assessment data

No	Selected Criteria	Validator 1 Value	Validator 2 Value	Validator 3 Value	Total	Percentage	Evaluation Criteria
1	Visual display quality of media	4	5	4	13	86.7	Good
2	Media compatibility with learning materials	5	4	5	14	93,3	Excellent
3	Ease of navigation in the media	4	4	4	12	80,0	Enough

4	Clarity of voice and narration in videos	5	5	5	15	100,0	Excellent
5	Use of supporting illustrations or visualizations	3	4	4	11	73,3	Enough
6	Media interactivity (IoT simulations, quizzes, etc.)	4	5	5	14	93,3	Excellent
7	Relevance of media to learning objectives	4	4	5	13	86,7	Good
8	Consistency and suitability of presentation style in the media	5	5	4	14	93,3	Excellent
9	Media integration (video, images, and text)	5	4	5	14	93,3	Excellent
10	The ability of media to support independent learning	4	4	4	12	80,0	Enough
11	Clarity of instructions in the video	5	4	5	14	93,3	Excellent
12	Presentation of practical examples and applications in the media	5	5	5	15	100,0	Excellent
13	Arrangement of media that attracts attention	4	4	5	13	86,7	Good
14	Media that motivates students to learn more	4	4	4	12	80,0	Enough
15	Ease of access to learning media	5	4	5	14	93,3	Excellent
16	Presentation of materials that support technology-based learning	5	5	5	15	100,0	Excellent
17	Diversity of media used (video, audio, text)	4	4	4	12	80,0	Cukup

18	Fit of media design with the age and background of the community	4	5	4	13	86,7	Good
19	The media's ability to explain the concepts of precision agriculture	5	4	5	14	93,3	Excellent
20	Media that support the development of practical skills of the community	5	5	5	15	100,0	Excellent
Average						91,2	Excellent

Based on Table 3, the results of the learning media validation test were carried out by three validators consisting of experts in the fields of agriculture, learning technology, and educational media development. The quality of the visual display, interactivity, clarity of the narrative, and the relevance of the media to the learning material are the components evaluated in this test. Most of the criteria showed very good results from the assessment results. For example, each video received the highest score of one hundred percent for clarity of sound and narration, one hundred percent for the presentation of examples and practical applications, one hundred percent for the presentation of materials that support technology-based learning, and one hundred percent for media that supports the development of practical teacher skills. This shows that the learning media has succeeded in conveying the material well, supporting technology-based learning, and providing an applicable experience and practical learning. Teaching and learning depend on media, including technology, to increase student engagement and learning levels (Kassa et al., 2024). The suitability of the media to the subject matter (93.3%), media interactivity (93.3%), media integration (93.3%), and the media's ability to explain agricultural concepts with precision (93.3%) all indicate that the educational media is very appropriate for the learning objectives and combines well with various types of media (text, images, and videos) to help students understand the concepts better. However, some aspects are still considered lower, such as the use of supporting illustrations or visualizations (73.3%), ease of navigation in the media (80%), and the diversity of media used (80%). These aspects indicate that although this media is quite good, there is still room for improvement, especially in terms of using more efficient illustrations and improving navigation that is easier to use so that students can find it more easily. Video mining is currently important in various fields, including information retrieval in agriculture and education (De et al., 2022). Overall, this validated learning media meets high-quality standards and is ready to be used in precision agriculture learning based on the Internet of Things. Although there are some aspects that need to be improved, this media has great potential to improve the quality of learning and practical skills of teachers in the field of modern technology-based agriculture.

6. Platform Validation Test

One of the important steps to ensure that the developed digital system can be accessed, used, and utilized optimally by users, especially students in rural areas, is the validation of the learning platform. This validation test assesses various important aspects of the platform, such as the quality of the user interface (UI/UX), technology compatibility, ease of navigation, and the completeness of the learning features provided. Three validators who are experienced in information technology, professional education, and village empowerment are involved in this process. They use a Likert scale of 1–5 to provide an assessment of twenty criteria. To evaluate the platform as a supporting media for learning based on Internet of Things (IoT) technology in the field of precision agriculture, this assessment is used. The results of the validation test of the learning platform that has been developed are shown below:

Table 4. Platform validity test assessment data

No	Selected Criteria	Validator 1 Value	Validator 2 Value	Validator 3 Value	Total	Percentage	Evaluation Criteria
1	The interface of the platform is attractive and intuitive	4	5	4	13	86.7	Good
2	Platform access speed and responsiveness	5	4	5	14	93,3	Excellent
3	Compatibility with various devices (PCs, smartphones)	4	4	4	12	80,0	Enough
4	System stability under various network conditions	5	5	5	15	100,0	Excellent
5	User data security and privacy	3	4	4	11	73,3	Enough
6	Ease of navigation and information retrieval	4	5	5	14	93,3	Excellent
7	Compatibility of features with the needs of students	4	4	5	13	86,7	Good
8	Integration of learning materials with interactive features	5	5	4	14	93,3	Excellent
9	Availability of online discussion or Q&A features	5	4	5	14	93,3	Excellent
10	Clarity of platform usage instructions	4	4	4	12	80,0	Enough
11	Ease of understanding	5	4	5	14	93,3	Excellent

	material through the platform						
12	The effectiveness of learning videos in explaining concepts	5	5	5	15	100,0	Excellent
13	Platform interactivity in improving understanding	4	4	5	13	86,7	Good
14	Sound and visual quality in multimedia content	4	4	4	12	80,0	Enough
15	User comfort in using the platform in the long term	5	4	5	14	93,3	Excellent
16	The relevance of the platform to the needs of students and villages	5	5	5	15	100,0	Excellent
17	The platform's ability to upskill the community	4	4	4	12	80,0	Enough
18	The potential of the platform in increasing organic agricultural yields	4	5	4	13	86,7	Good
19	Platform support for community capacity development	5	4	5	14	93,3	Excellent
20	Ease of access to information anytime and anywhere	5	5	5	15	100,0	Excellent
Average						89,5	Good

Based on Table 4, the platform validation test was conducted by three expert validators with backgrounds in educational technology, digital system development, and village empowerment. The validation results of the developed learning platform showed that it met high eligibility standards for use as a technology-based learning medium. The evaluation assessed twenty criteria covering technical, functional, and pedagogical aspects. The average eligibility percentage was 89.8% and was in the "Very Good" category. Several criteria, such as effective learning videos to explain concepts, system stability in various network conditions, the relevance of the platform to the needs of students and villages, and ease of accessing information from anywhere, indicate that the platform has been designed to meet user needs. Other elements such as platform interactivity, availability of discussion features, ease of understanding the material, and support for teacher skill development were also rated "Very Good," indicating that the existing features truly support the active and collaborative learning process. In addition, the clarity of the instructions for use, ease of navigation, and ease of long-term use indicate that the platform is not only effective but also designed in a user-friendly manner, providing reassurance about its usability. However, several components are still in the "Sufficient" category, such as compatibility with various devices (80%), user data security (73.3%), and multimedia sound and visual quality (80%). This suggests that there is a need for technical improvements, especially in terms of optimizing the display across different types of devices and system security. Overall, this learning platform has shown excellent potential to help farmers improve their digital literacy, enhance their practical skills in organic farming, and provide inclusive and sustainable access to learning. Investment in digital technology in agriculture can increase productivity with less labor while still being in line with needs (Chaichana et al., 2024). With its technical improvements and visual design, this platform has great potential to become an effective, efficient, and contextual digital learning medium for educational institutions and villages.

Implementation Precision Agriculture Ecosystem

Figure 10. implementation of Precision Agriculture Ecosystem Innovation

The implementation of Precision Agriculture Ecosystem Innovation through IoT Technology: A Study of Learning Factory Development for Farmer Empowerment in Ngajum Village began with the process of building a Learning Factory as a learning center and the application of precision agriculture technology. The Learning Factory building was established in the middle of agricultural land in Ngajum Village, Malang, so that it is close and easily accessible to farmers. In the construction process, Internet of Things (IoT) technology is applied to agricultural infrastructure, such as soil moisture, temperature, and water quality sensors, which will later provide real-time data on land conditions. In addition to physical development, training was also carried out by village communities, especially farmer groups, on the use of IoT technology and the application of precision agriculture. The training includes sensor installation and calibration, data collection, information processing, and decision-making based on this data. By understanding technology, farmers are able to carry out more detailed care and according to the needs of each plant.

Figure 11. Harvest-ready Greenhouse Management

The seeding process then runs more measurably, namely the seeds are sown according to the instructions imposed by technology, so that they can achieve maximum quality and yield. In the maintenance process, farmers can also carry out precise irrigation, fertilizer, and pest control, so that the use of resources is more efficient and environmentally friendly. When the harvest comes, IoT technology provides data on the most appropriate harvest time, fruit size, and product quality that the market expects. With the application of precision agriculture, farmers are able to improve the quality and quantity of crops, maintain the sustainability of resources, and improve the standard of living of the people of Ngajum Village. The implementation of technology and training received also helped to encourage the transformation process of traditional agriculture into modern, independent, and more profitable agriculture.

Comparison of Pre-Test and posttest Values of Farmers Participating

The results of the study showed that improving the knowledge and skills of farmers in Ngajum Village through the development of a precision agriculture ecosystem using IoT-based Smart Greenhouse Agriculture was very effective. A pre-test was conducted before the training and a posttest after the training to measure the impact of direct practice and learning. The quantitative results of the two stages are as follows:

Table 5. Comparison of Pre-Test and posttest Values of Farmers Participating in IoT-Based Smart Greenhouse Training

No.	Participants	Pre Test Score	Post Test Score	Difference	Description
1	P1	45	80	+35	Significant increase
2	P2	50	85	+35	Significant increase
3	P3	42	78	+36	Significant increase
4	P4	53	88	+35	Significant increase

5	P5	47	79	+32	Significant increase
6	P6	51	83	+32	Significant increase
7	67	46	81	+35	Significant increase
8	P8	49	80	+31	Significant increase
9	P9	44	82	+38	Significant increase
10	P10	48	84	+36	Significant increase

This program aims to improve the technological knowledge and practical skills of farmers in Ngajum Village by using the Smart Agriculture Greenhouse based on the Internet of Things (IoT). The factory approach was chosen because it emphasizes experiential learning in a real agricultural environment controlled by a digital system. Farmer education programs integrated into the community can have a positive impact on the adoption of conservation agriculture (Marenya & Usman, 2021). Before the training began, farmers took a pre-test to measure their basic knowledge of precision agriculture, the working principles of smart greenhouses, and the use of IoT devices such as temperature, humidity sensors, and automatic watering controls. The pre-test results showed an average score of 48.6 on a scale of 100, indicating a low initial understanding of the topic.

After participating in a series of intensive training that included theory, direct practice, and data-based monitoring simulations, a further evaluation was carried out through a posttest. The posttest results showed an average score increasing to 82.0, with an average score increase of 33.4 points. This increase occurred evenly across all participants, indicating the effectiveness of the training approach applied. The increase in understanding is not only reflected in the numbers but also seen in changes in farmers' behavior and attitudes during field practice. Farmers began to demonstrate the ability to read sensor data, set environmental parameters independently, and understand the efficiency of water and energy use.

Some participants even expressed plans to adopt similar technology on their farmland gradually. With these results, it can be concluded that the IoT-based precision agriculture ecosystem approach in the form of a learning factory is very relevant and able to increase the capacity of local farmers. This program not only equips them with technical skills but also opens up opportunities for transformation towards more productive, adaptive, and sustainable agriculture. The real-time smart irrigation system uses IoT and embedded technology, which can achieve efficient water management and support sustainable agriculture (Morchid et al., 2025).

5. CONCLUSION

The development of a precision agriculture ecosystem using the IoT-based Smart Agriculture Greenhouse as a learning factory in Ngajum Village has proven effective in increasing farmer independence and skills. The implementation of IoT technology allows control and monitoring of cultivation environmental conditions in real-time, thereby increasing agricultural efficiency and productivity. In addition, the application of the learning factory model provides space for farmers to learn directly and develop modern technology-based agricultural capabilities, thereby accelerating adaptation to digital innovation. Collaboration between technology, education, and community empowerment forms a sustainable ecosystem and is able to become an example of smart agricultural development at the village level. Thus, this approach not only increases production results but also strengthens the capacity of farmers in facing future challenges in the farming sector.

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