Mattawang: Jurnal Pengabdian Masyarakat *ISSN: 2746-5233 (online)*
Vol. 6 No. 3 (2025)
https://doi.org/10.35877/454RI.mattawang4277

PKM: Transformation of Geography Learning through Unmanned Aerial Vehicles – A Creative Solution to Enhance the Quality of Digital Mapping at SMA Negeri 3 Takalar

PKM Transformasi Pembelajaran Geografi melalui Unmanned Aerial Vehicle: Solusi Kreatif untuk Peningkatan Kualitas Pemetaan Digital di SMA Negeri 3 Takalar

Erman Syarif[a,*], Fathahillah[b], & Abd Malik[a]

[a]*Geography Education Study Program, Faculty of Mathematics and Natural Sciences, Universitas Negeri Makassar, Jl. Mallengkeri, UNM Parangtambung Campus, Makassar City, Indonesia*
[b]*Economy Education Study Program, Faculty of Economy and Bussiness, Universitas Negeri Makassar, Jl. AP. Pettarani, Makassar City, Indonesia*

Abstract

This Community Service Program (PKM) aims to transform geography learning through the utilization of Unmanned Aerial Vehicle (UAV) technology as a creative solution to enhance the quality of digital mapping at SMA Negeri 3 Takalar. The activities were carried out in several stages: needs analysis, technical training on UAV operation and mapping software, field practice mentoring, and evaluation of improvements in teachers' and students' competencies. The application of UAVs equipped with GPS and high-resolution cameras, combined with ArcGIS software, enabled mapping learning to become more interactive, contextual, and project-based. The evaluation results showed a significant increase in both teachers' and students' knowledge and skills in operating UAVs, processing spatial data, and producing digital thematic maps. The program also fostered greater student interest in learning and strengthened teachers' capacity to integrate geospatial technology into the geography curriculum. This PKM recommends the continuation of training and curriculum development based on technology to support spatial literacy at the secondary school level.

Abstrak

Program Pengabdian kepada Masyarakat (PKM) ini bertujuan untuk mentransformasi pembelajaran geografi melalui pemanfaatan teknologi Unmanned Aerial Vehicle (UAV) sebagai solusi kreatif dalam peningkatan kualitas pemetaan digital di SMA Negeri 3 Takalar. Kegiatan dilaksanakan melalui beberapa tahapan, yaitu analisis kebutuhan, pelatihan teknis penggunaan UAV dan perangkat lunak pemetaan, pendampingan praktik lapangan, serta evaluasi peningkatan kompetensi guru dan siswa. Penerapan UAV yang dilengkapi GPS dan kamera beresolusi tinggi dipadukan dengan perangkat lunak ArcGIS, sehingga proses pembelajaran pemetaan menjadi lebih interaktif, kontekstual, dan berbasis proyek. Hasil evaluasi menunjukkan adanya peningkatan signifikan pada pengetahuan dan keterampilan guru maupun siswa dalam mengoperasikan UAV, mengolah data spasial, serta menyusun peta tematik secara digital. Program ini juga meningkatkan minat belajar siswa serta memperkuat kapasitas guru dalam mengintegrasikan teknologi geospasial ke dalam kurikulum geografi. PKM ini merekomendasikan keberlanjutan pelatihan dan pengembangan kurikulum berbasis teknologi untuk mendukung literasi spasial di tingkat sekolah menengah.

Keywords: Transformation of Geography Learning; Unmanned Aerial Vehicle; Digital Mapping; SMA Negeri 3 Takalar.

1. Introduction

Geography education in the digital era requires innovative learning approaches that integrate technology with concepts of space and environment. As a subject closely related to mapping, observation, and spatial analysis,

* Corresponding author:
E-mail address: ermansyarif@unm.ac.id

geography demands contextual, applicable, and technology-based methods. The development of information and communication technology, particularly in digital mapping, offers significant opportunities to optimize the quality of geography learning in schools. Through the use of technology, teachers not only gain theoretical knowledge but also enhance practical skills in reading, interpreting, and processing spatial data. This aligns with the demands of the 21st century, which emphasize digital literacy, critical thinking, and collaborative skills in solving environmental and spatial problems (Syarif, Maddatuang, et al., 2022; Nurjannah et al., 2020; Danardono et al., 2022). Thus, the integration of digital technology in geography learning is expected to improve the relevance, effectiveness, and attractiveness of the teaching and learning process.

One relevant and innovative technology in geography education is the Unmanned Aerial Vehicle (UAV) or drone. UAVs provide teachers with the opportunity to gain hands-on experience in spatial data acquisition, image processing, and the interpretation of digital maps with greater accuracy and efficiency. The use of UAVs extends learning beyond classroom theory, integrating it with field practices that foster observation skills, spatial analysis, and deeper understanding of spatial and environmental dynamics (Arijuddin et al., 2025). Moreover, UAVs support the development of technological and data literacy, which are crucial in the era of the Fourth Industrial Revolution and Society 5.0, where critical thinking, collaboration, and adaptability to advanced technology are key competencies. Therefore, UAVs function not only as a learning medium but also as a strategic tool to equip teachers in addressing global challenges in the fields of geospatial science and environmental studies.

Figure 1. Observation and interview with teachers at SMA Negeri 3 Takalar

Geography learning at SMA Negeri 3 Takalar still faces challenges in utilizing advanced technologies, particularly in the aspect of digital mapping. Until now, teachers have primarily relied on atlases, globes, or static satellite imagery without direct involvement in spatial data collection. This condition has limited their understanding of mapping concepts and reduced their technical skills in processing geospatial data. Such skills, however, are highly important in today's digital era, especially given the rapid development of Geographic Information Systems (GIS) and modern tools such as Unmanned Aerial Vehicles (UAVs) (Gadeng et al., 2022). Therefore, innovation in geography education is urgently needed—one that emphasizes not only theoretical aspects but also provides practical experiences in collecting, processing, and interpreting spatial data.

This situation requires a transformation of learning that bridges theory with technology-based practice. UAVs can serve as creative learning media to help teachers better understand the fundamentals of mapping, spatial analysis, and digital data management. In this way, geography learning is not limited to the cognitive domain but also develops teachers' skills (psychomotor) and scientific attitudes. Furthermore, the use of UAVs can foster curiosity, enhance problem-solving abilities, and cultivate collaborative character through teamwork in various stages of spatial data collection and processing (Malik et al., 2021; Syarif, Saputro, et al., 2022).

The implementation of UAVs in geography learning is in line with the Merdeka Belajar policy, which emphasizes meaningful, creative, and innovative learning experiences. Through digital mapping practices using UAVs, teachers are not only encouraged to think critically and collaborate but also to strengthen their problem-solving abilities in real-world contexts. The resulting digital maps can be applied for various purposes, such as environmental analysis, spatial planning, and disaster mitigation (Roziqin et al., 2023; Abbas et al., 2021; Syarif, 2021). Hence, UAV-based learning is expected to increase teachers' motivation and interest in geography while developing 21st-century skills relevant to the Fourth Industrial Revolution and Society 5.0.

In addition, SMA Negeri 3 Takalar has surrounding environmental potential that strongly supports the implementation of UAVs in geography education. The existence of coastal areas, agricultural land, and residential zones provides rich contextual learning resources that can serve as direct mapping objects for teachers. This potential opens opportunities for the application of Project-Based Learning (PjBL), which not only provides authentic experiences but also encourages teachers to think critically, collaborate, and produce spatial data useful for both the school and the local community (Umroh et al., 2024).

Mastery of digital mapping skills through UAVs carries strategic value in preparing teachers to face the era of globalization. In the future, demand for professionals skilled in digital mapping technology is projected to increase across fields such as geography, spatial planning, natural resource management, and disaster mitigation. Therefore, integrating UAVs into geography education is not only beneficial for enhancing academic understanding but also relevant to workforce demands and sustainable development needs. Moreover, teachers become accustomed to adapting to technological changes, thinking critically, and producing practical digital maps that can serve local communities (Supratman et al., 2023).

However, the use of UAVs in schools remains relatively limited, due to both lack of facilities and teachers' limited knowledge of this technology. This situation highlights the need for innovative efforts to bridge the gap between technological potential and classroom practice. For this reason, a Community Service Program (PKM) is proposed to provide creative solutions for integrating UAVs into geography education at SMA Negeri 3 Takalar. The program emphasizes not only the introduction of UAV technology but also practical assistance, enabling teachers to independently operate UAVs, understand the digital mapping workflow, and process the resulting spatial data. In this way, the program is expected to improve the quality of learning while fostering 21st-century skills relevant to science and technology development.

This program is also expected to serve as a model of innovative geography education that can be replicated in other schools, especially those facing similar challenges in adopting digital technology. By demonstrating the effectiveness of UAVs in improving digital mapping quality, the program has the potential not only to broaden teachers' knowledge and skills but also to encourage the emergence of more creative, collaborative, and sustainable technology-based teaching practices, thereby strengthening the educational ecosystem in the digital era (Sekarsih et al., 2025).

2. Methods

To address the challenges faced by the partner, namely the teachers of SMA Negeri 3 Takalar, this Community Service Program (PKM) was designed using a systematic approach. The methods employed include observation and interviews to identify needs and initial conditions, training/workshops as a means of improving competencies, the application of technology to support learning transformation, mentoring and evaluation to ensure successful implementation, as well as sustainability planning to maintain the outcomes achieved. The workflow of this community service shown on Figure 2.

2.1. Preparation Stage

a) Program Socialization with Partner.

The PKM team introduced the program to the partner to obtain approval. A direct meeting was held at SMA Negeri 3 Takalar to explain the objectives, benefits, and implementation mechanisms of the PKM program to the teachers. Feedback, suggestions, and input were collected from the partner to improve program quality and engagement.

b) Observation and Identification of Partner's Problems.

Through field surveys, the PKM team identified the partner's main problems, particularly in the learning process at school. This activity included classroom observation and interviews with teachers regarding challenges in teaching. After identifying the problems, the team jointly formulated solutions and program designs.

c) Designing Training and Mentoring Programs for the Partner.

The PKM team and SMA Negeri 3 Takalar conducted a Focus Group Discussion (FGD) to design a program addressing learning challenges. The primary focus of the program was improving the quality of geography learning through the use of Unmanned Aerial Vehicle (UAV) technology or drones. This initiative was designed to strengthen

teaching competencies, particularly in mapping and remote sensing, while preparing students with relevant skills for the future workforce.

d) Developing Training and Mentoring Materials

This activity included:

- Preparing handouts and presentation materials for training participants as summaries of the modules to be delivered.
- Designing a satisfaction survey instrument to measure the effectiveness of the PKM program.
- Preparing evaluation instruments aimed at identifying program weaknesses and shortcomings, to improve the quality of future implementations.

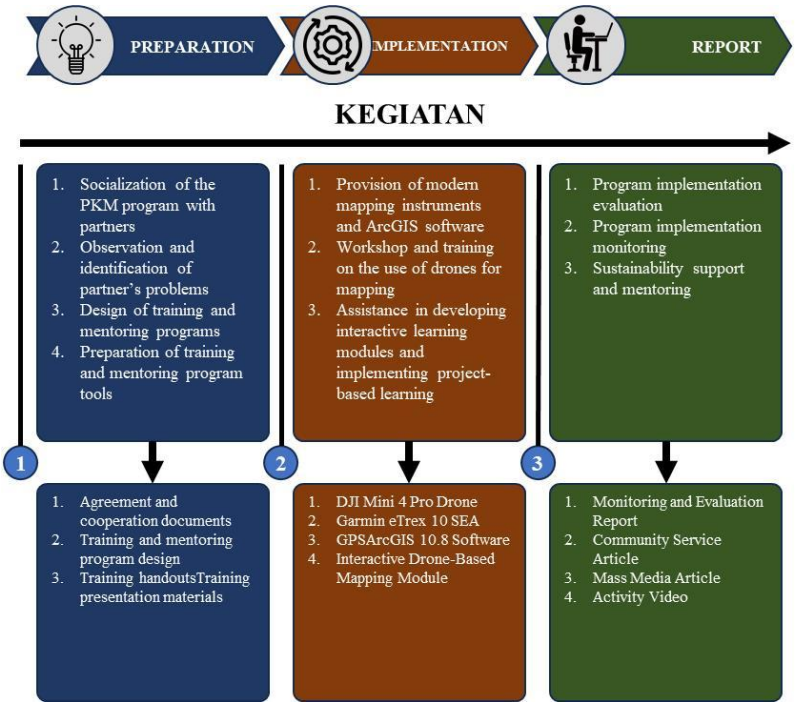


Figure 2. Community Service Workflow

2.2. Implementation Stage

a) Provision of Modern Mapping Tools and ArcGIS Software

This activity involved providing modern mapping tools such as the DJI Mini 4 Pro Drone (DJI RC-2), Garmin GPSMAP 65s, and installing mapping software such as ArcGIS 10.8 on school computers to be used in teaching and learning activities.

b) Workshop and Training on Drone Usage for Mapping

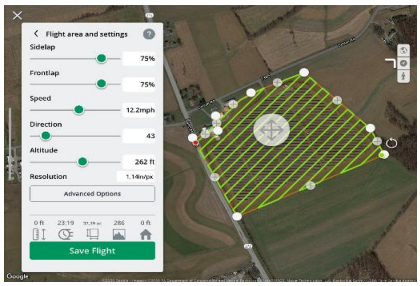
A workshop was held to provide basic knowledge about drones, including their principles of operation and applications in mapping, particularly for educational purposes at SMA Negeri 3 Takalar. The session continued with hands-on training, allowing teachers to directly practice using drones, including flight planning, operation, data collection, and mapping result analysis. Teachers learned how to plan and carry out mapping missions using drones, as well as process the collected data for educational purposes.

c) Mentoring in the Development of Interactive Learning Modules and the Implementation of Project-Based Learning

The program provided mentoring and technical guidance for teachers in designing and developing interactive learning modules that utilize drones to help students better understand abstract mapping concepts. This activity began with an initial analysis stage, which included content analysis, analysis of learning tools and instruments, and analysis of

learning objectives. After completing the initial analysis, the team proceeded with developing learning modules aligned with curriculum objectives.

1. Perencanaan Terbang *(Flight Plan)*



2. Pemasangan dan Pengukuran *(Premark)*

3. *Data Aqcuisition*

4. *Image Processing*

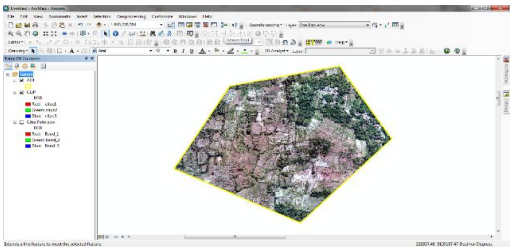


Figure 3. Process of Mapping

The development of these modules was enriched with outputs from drone-based mapping activities to make mapping concepts more comprehensible to students. Once the modules were completed, the program continued with mentoring and technical guidance to support teachers in implementing project-based learning activities using drones. This included the integration of Unmanned Aerial Vehicle (UAV) technology into the curriculum and the use of drone-generated data for classroom learning activities.

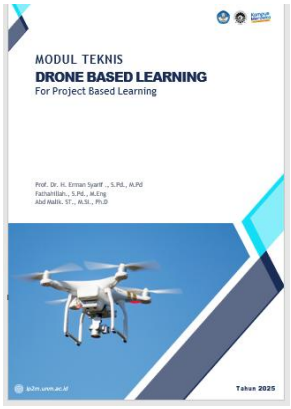


Figure 4. Learning Module Design

2.3. Reporting Stage

a) Program Implementation Evaluation

The evaluation stage was carried out regularly and periodically during the PKM activities. This evaluation aimed to ensure that the program ran smoothly, maintained implementation quality, achieved the set objectives/targets, and had a measurable impact on the partner. During this stage, feedback from the partner was collected to identify areas

requiring improvement. After completing the training activities, participants were asked to fill out a satisfaction survey.

b) Program Implementation Monitoring

Monitoring was conducted periodically to oversee the implementation of interactive and engaging mapping lessons based on Unmanned Aerial Vehicle (UAV) or drone technology at the school. This was done to ensure that the teaching process aligned with the intended learning objectives. Further analysis and assessment were conducted to evaluate the effectiveness of drone-based mapping lessons that had been implemented.

c) Program Sustainability

This stage aimed to ensure that the PKM program remained sustainable after its completion. Following the implementation of the program, the PKM team was responsible for providing continuous mentoring to the partner in addressing challenges encountered during the application of drone-based mapping lessons. Teachers were also encouraged to participate in additional training workshops on drones and to establish a drone community at SMA Negeri 3 Takalar. Continuous mentoring was conducted for one year after the completion of PKM activities. The roadmap for program sustainability can be seen in Figure 5.

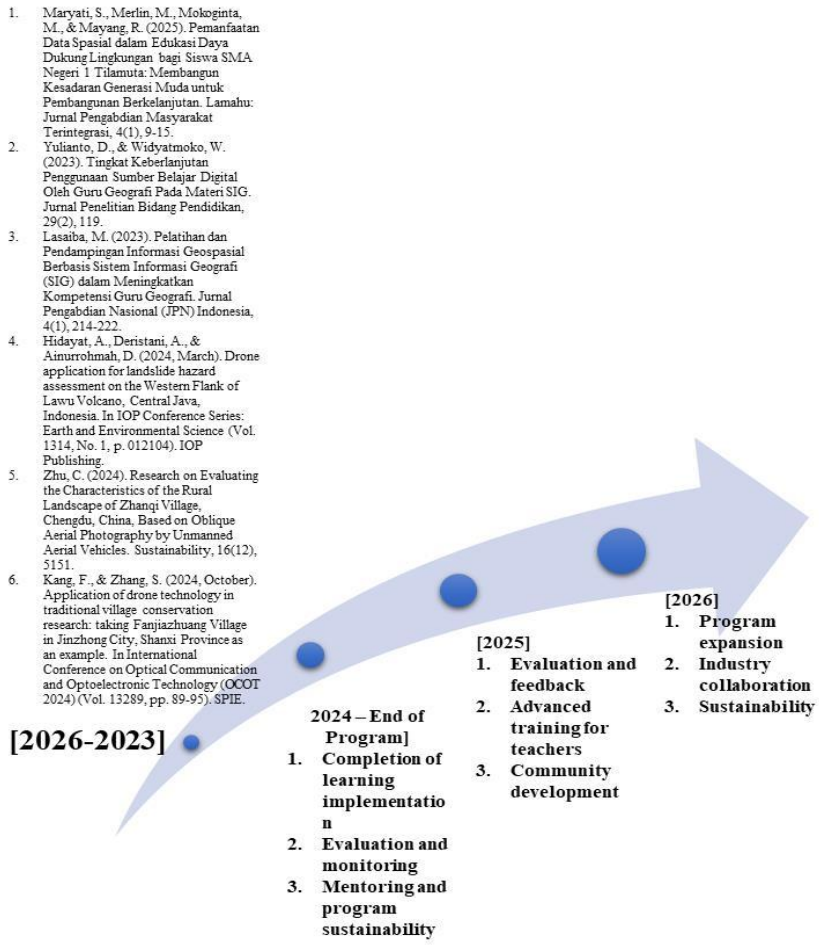


Figure 5. The roadmap for program sustainability

d) Partner Participation

The participation of the partner in this program included providing space and facilities for training and mentoring, as well as actively engaging in all stages of the PKM program implementation. They attended the PKM socialization sessions, workshops, and training activities, provided feedback and suggestions for the program, and offered support and collaboration throughout the implementation process.

e) Roles and Responsibilities of Each Team Member

The team consisted of lecturers from three study programs: Geography Education (1 member), Statistics (1 member), and Geography (1 member). In addition, five students from the Geography Education Study Program were also involved in the program.

3. Result and Discussion

3.1. Result

The implementation of the Community Service Program (PKM) at SMA Negeri 3 Takalar successfully achieved several key outcomes aligned with the predetermined objectives. This program not only made a tangible contribution to improving the quality of learning but also strengthened collaboration between the university and the partner school. The outcomes achieved from the implementation of this program can be outlined as follows:

3.1.1. Improvement of Teachers' Knowledge and Skills in Using UAV Drones for Mapping Lessons

Through intensive training sessions, most geography teachers successfully acquired fundamental skills in operating drones for digital mapping. A total of 20 geography teachers participated in a two-day training program held on July 27–28, 2025. The training materials covered two main aspects: (1) drone operation for spatial data acquisition, and (2) the use of ArcGIS 10.8 software for processing and analyzing mapping data.

Participants not only gained theoretical understanding but also engaged in hands-on field practice on how to plan and carry out mapping missions. In addition, teachers were trained to process drone-collected data to produce accurate thematic maps using ArcGIS 10.8. With these skills, teachers are expected to transfer their knowledge and experience to students, thereby making geography learning more contextual, innovative, and aligned with current technological developments.

The stages of the workshop and training on drone use for mapping included the following:

(1) Opening Session and Introductory Materials on Drones

The training began in the auditorium of SMA Negeri 3 Takalar in an atmosphere of enthusiasm. The event was officially opened by the Principal of SMA Negeri 3 Takalar, Mr. Ilham, S.Pd., M.Pd., who expressed his appreciation and full support for the implementation of this PKM as an effort to enhance teachers' competencies in utilizing modern technologies for geography education. Following the opening remarks, the session continued with the presentation of introductory materials on drones, which included an overview of their functions, benefits, and potential applications in mapping and project-based learning. This introductory session aimed to provide participants with a foundational understanding of the vital role drone technology plays in supporting geography lessons that are more interactive, practical, and relevant to the demands of the 21st century.

Figure 6. Opening Ceremony

Figure 7. Training Participants

2) Introduction to Drone Features

This session introduced participants to various drone features and their respective functions in a comprehensive manner. The materials delivered included the camera system, covering aspects such as resolution, stabilization, zoom, and shooting modes that can be utilized to produce high-quality images and videos. Participants were also introduced

to the flight system, consisting of GPS, barometer, ultrasonic sensors, and the Inertial Measurement Unit (IMU), all of which play crucial roles in maintaining drone stability during flight. In addition, participants studied the drone control system, which involved the use of the remote controller, waypoint settings, return-to-home function, and geofencing features designed to ensure flight safety. The session also provided an overview of the drone battery components, including capacity and effective recharging time estimation.

Importantly, the activity incorporated hands-on practice, where participants learned how to power on and connect the drone with the remote controller. Thus, the participants not only gained theoretical understanding but also developed the ability to apply these skills in real-life operations. This stage was expected to enhance participants' technical competence in operating drones safely, effectively, and professionally.

Figure 8. Introduction to Drone Features

Figure 9. Drone Activation

(3) Flight Planning

This session included training on flight planning, a crucial stage in the drone-based mapping process. Participants were guided to identify and delineate the specific school areas to be mapped according to project needs. They were then trained to define key flight parameters, including flight altitude, speed, image overlap rate, and desired image resolution, in order to ensure that the resulting maps were both accurate and in line with professional standards.

In addition, participants learned to design automated flight routes using the DJI flight planning application (DJI Pilot). Through this application, flight paths could be systematically arranged so that the drone could operate autonomously along predetermined routes without requiring manual control. This structured planning significantly enhanced the efficiency of the mapping activities while minimizing the potential for technical errors during data acquisition in the field.

Figure 10. Flight Plan

Figure 11. Designing the Flight Path

(4) Data Acquisition

At this stage, participants practiced data acquisition by operating the drone within the designated school area. The flight was conducted automatically, following the pre-designed flight path generated through the planning application. During the flight, the drone systematically captured aerial images at regular intervals in accordance with the set parameters.

To ensure the quality of the output, the flight was closely monitored in real time, including checks on drone stability and image capture consistency. Particular attention was given to maintaining an adequate level of image overlap, which is essential for post-processing. High-quality overlapping images serve as the foundation for generating accurate 3D models and digital maps, enabling further spatial analysis and supporting geospatial learning applications.

Figure 12. Drone Flight

Figure 13. Drone Monitoring During Flight

(5) Data Processing and Map Layouting

The data processing stage began with the transfer of aerial photographs captured by the drone into a computer for further analysis. Participants were trained to process the imagery using a combination of digital mapping software, including DJI Pilot, Pix4D, and Agisoft Metashape, which are widely recognized in geospatial applications.

The processing workflow consisted of the following steps:

a. Ground Control Points (GCP) marking – Participants learned to identify and mark GCPs as spatial reference benchmarks, ensuring high positional accuracy in the georeferencing process.
b. Point cloud generation – The collected photographs were aligned and reconstructed into a 3D point cloud, providing a detailed spatial representation of the mapped area.
c. 3D model construction – Based on the point cloud, a three-dimensional model was generated to visualize topography and surface features with greater precision.
d. Orthophoto creation – A 2D orthophoto map was produced through orthographic projection, resulting in a uniform-scale image suitable for spatial analysis.
e. Map layouting with ArcGIS 10.8 – Finally, participants applied cartographic design techniques using ArcGIS 10.8 to create a well-structured orthophoto map layout. This final product was prepared for presentation and for direct integration into geography learning activities.

Through this stage, teachers not only acquired technical skills in UAV data processing but also gained practical experience in producing thematic maps that can enhance classroom instruction and project-based learning.

Figure 14. Data Processing

Figure 15. Map Layouting Using ArcGIS 10.8

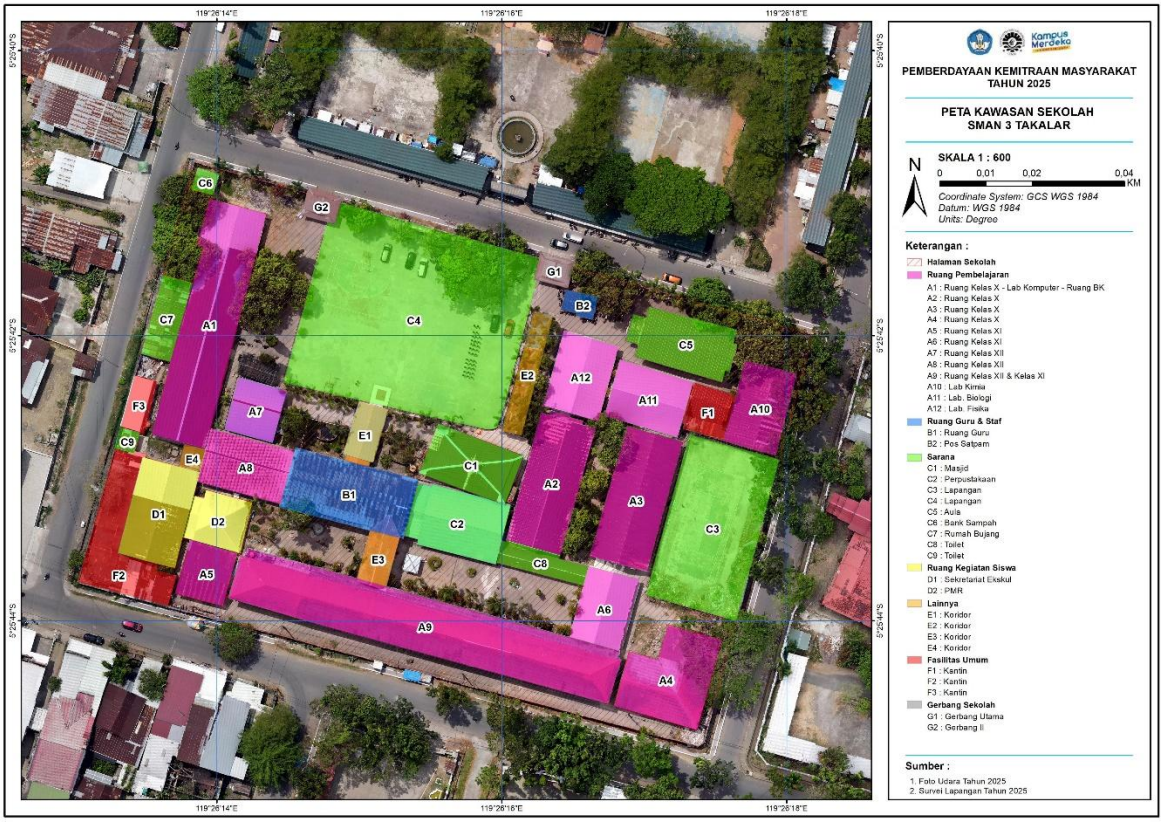


Figure 16. Output Map of the Training

The results of the pre-test and post-test showed a significant improvement in participants' understanding and skills. The average pre-test score was 45.22, while the post-test score increased to 89.53, indicating a 97.98% improvement.

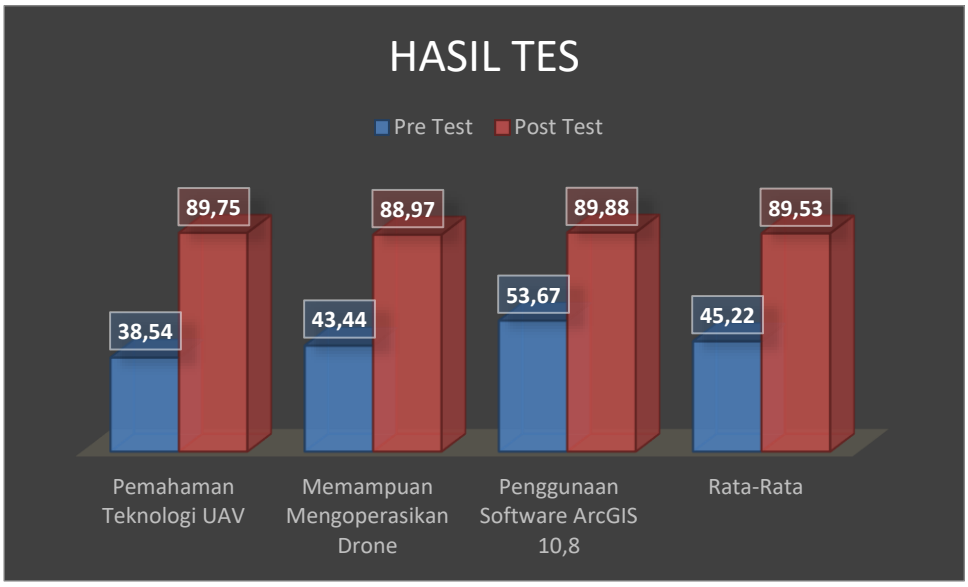


Figure 17. Test Results Diagram

Table 1. Percentage of Teacher Satisfaction After the Training

No	Indicator	Percentage of Teachers Agreeing
1	he training was very useful	97%
2	Confidence in implementing UAV	90%

Figure 18. Development of an Interactive Learning Module Based on Drone Technology

Figure 19. Assistance in Implementing Drone Technology

The assistance provided in developing a more interactive and engaging mapping learning method was carried out through the preparation of an interactive learning module based on drone technology. This module was tested in the classroom and showed positive results. Students became more interested and actively engaged in the teaching and learning process, especially in understanding mapping concepts that had previously been abstract. The visualization produced by UAV technology provided a more tangible learning experience, enabling students to connect theory with field practice. Thus, this module has proven effective not only in improving students' understanding of the material but also in fostering their learning motivation and critical thinking skills.

The application of project-based learning methods encouraged students to actively participate in all stages of mapping, from planning and data collection to results analysis. The implementation of drone technology in the teaching and learning process has been shown to increase students' interest in Geography. Students demonstrated high enthusiasm in participating in practical sessions and project-based learning activities using UAVs (Unmanned Aerial Vehicles).

Based on a survey conducted after the implementation of this method, 95% of students stated that learning with UAVs was more engaging, 89% felt they gained a better understanding of mapping concepts, and 85% actively participated in the mapping project. These findings indicate that integrating drone technology not only makes the learning process more contextual and enjoyable but also strengthens students' spatial understanding. Moreover, project-based learning through UAVs fosters collaboration, problem-solving, and critical thinking skills, which are essential for addressing the challenges of 21st-century education.

Table 2. Survey on the Implementation of Project-Based Learning Method

No	Indikator	Percentage of Students Agreeing
1	Found learning with UAV more engaging	95%
2	Felt better understanding of mapping concepts	89%
3	Active participation in mapping project	85%

3.1.2. Enhancement of Mapping Learning Media Based on Unmanned Aerial Vehicle (UAV) Technology

The implementation of science and technology (IPTEKS) at SMA Negeri 3 Takalar was focused on the use of modern drones equipped with GPS technology and high-resolution cameras, as well as the utilization of ArcGIS software to support learning activities, particularly in mapping materials. The use of these tools aimed to provide students and teachers with a more interactive, contextual, and applicable learning experience, especially in Geography subjects. The disseminated technologies included the DJI Mini 4 Pro drone, ArcGIS 10.8 software, and the Garmin Etrex 10 GPS, all designed to facilitate the processes of data collection, processing, and spatial analysis. This technological integration enabled students to practice flight path planning, field data acquisition, and digital mapping directly, thus bringing the learning process closer to professional practices. Moreover, the implementation of this IPTEKS initiative is expected to enhance technological literacy, critical thinking skills, and students' readiness to face future challenges in data-driven spatial industries.

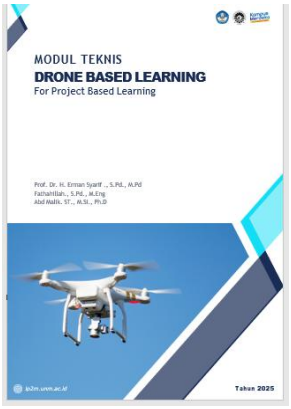


Figure 20. Development of an Interactive Learning Module Based on Drone Technology

Figure 21. Classroom Trial of the Module

The availability of modern mapping tools such as the DJI Mini 4 Pro drone and the Garmin Etrex 10 SEA GPS has been effectively utilized in Geography learning. The use of these devices not only supported teaching efficiency but also enriched students' learning experiences by providing more interactive and practical field-based activities. Through the integration of this technology, students acquired practical knowledge that is relevant to the demands of the workforce, particularly in the fields of mapping, geospatial studies, and spatial analysis. This, in turn, fostered improvements in competence, technical skills, and preparedness for the challenges of technological advancement in the digital era.

3.2. Discussion

The implementation of this PKM program made a significant contribution to improving teachers' skills in operating the DJI Mini 4 Pro drone and using ArcGIS 10.8 software. The results showed that the training materials were systematically designed and highly relevant to teachers' needs, making them easier to adapt in Geography teaching. Pre-test and post-test data revealed a substantial improvement: the average pre-test score of 45.22 increased to 89.53 in the post-test, equivalent to a 97.98% gain. These findings confirm that a structured, practice-based, and field-oriented training approach can significantly enhance teachers' competencies. The improvement not only strengthened teachers' mastery of mapping technology but also boosted their confidence in applying more interactive teaching methods. This, in turn, is expected to positively affect the quality of instruction, particularly in enriching geospatial technology-based Geography learning in the classroom (Gadeng et al., 2022).

The learning module developed in this program proved effective in improving students' understanding, particularly for those who previously struggled with abstract mapping concepts. The use of drone technology and mapping software created a concrete, practical, and interactive learning experience, allowing students to connect theory with field practice more easily. Based on surveys completed by students after the implementation of UAV project-based learning, findings showed that 95% of students considered UAV learning more engaging, 89% felt they gained a better understanding of mapping concepts, and 85% actively participated in mapping project activities. These data indicate that integrating geospatial technology into the learning process can enhance motivation, participation, and mastery of spatial concepts. Previous studies also confirm that technology-based learning can help students overcome difficulties in understanding complex materials, as it allows them to visualize, analyze, and interpret data directly (Teixeira et al., 2023). Thus, the application of drones and mapping software in the classroom not only enriches learning strategies but also fosters critical thinking, problem-solving skills, and preparedness for the workforce in the fields of geography and geospatial technology.

The success of this program cannot be separated from the active participation of its partner, SMA Negeri 3 Takalar, which was fully involved in every stage of implementation—from socialization, preparation, and execution to program evaluation. Strong collaboration between the proposing team and the partner school contributed greatly to achieving optimal results consistent with PKM objectives. To ensure sustainability, continuous mentoring is required

through additional training or competency-strengthening workshops so that teachers can keep updating their knowledge and skills in line with advances in geospatial technology. Furthermore, the integration of drone technology into the school curriculum should be supported by institutional policies that allow UAVs to be used more broadly, not only in Geography but also in other relevant subjects such as science, information technology, and environmental education.

Therefore, this PKM program not only succeeded in improving the quality of Geography teaching at SMA Negeri 3 Takalar but also introduced an innovative learning model that can be adopted and replicated by other schools with similar needs. This success represents an important foundation for developing a technology-based learning ecosystem that is adaptive to the challenges of the 21st century.

4. Conclusion

The implementation of the Community Service Program (PKM) at SMA Negeri 3 Takalar successfully achieved its intended goals, as evidenced by significant improvements in the quality of Geography learning. The program effectively addressed the limitations of teaching media as well as the lack of teacher skills and knowledge in utilizing modern mapping technologies, particularly UAVs (drones) and ArcGIS software. Through training, mentoring, and direct classroom implementation, teachers gained both practical understanding and field-based experiences that are highly relevant to the demands of 21st-century education. The integration of UAV and ArcGIS technology into the teaching and learning process not only enriched instructional methods but also enhanced student motivation and participation through project-based learning that is more interactive, applicable, and contextual. This achievement marks an important step in driving the transformation of Geography education toward a more digital, collaborative, and field-oriented approach, while preparing both teachers and students to engage with future developments in geospatial technology.

Structured and intensive training significantly improved teachers' skills in operating the DJI Mini 4 Pro drone and using ArcGIS software, as demonstrated by post-test scores that nearly doubled compared to pre-test results. This achievement confirms that practice-based training approaches can effectively transfer technical skills to teachers. The implementation of UAV-based learning modules also proved effective in strengthening students' understanding of mapping concepts, which had previously been considered difficult. The use of drone technology enabled students to observe, record, and analyze geospatial phenomena directly, transforming abstract concepts into more concrete and contextual knowledge.

Furthermore, the program succeeded in increasing students' interest and enthusiasm for learning; the majority of students stated that technology-based learning was more engaging, improved their comprehension, and encouraged active participation. Field mapping with drones provided hands-on learning experiences relevant to the professional world, recognized by both students and teachers as a progressive step in the teaching and learning process.

Overall, this PKM program not only improved teacher and student competencies but also provided an innovative learning model that can be adopted and replicated by other schools. Its success highlights the vital role of integrating modern technology into curricula to enhance the quality of education while equipping students with relevant 21st-century skills. To ensure sustainability, it is recommended to conduct follow-up training, periodic mentoring, and supportive school policies so that these positive outcomes can be further strengthened and serve as inspiration for the broader development of technology-based Geography education.

Acknowledgements

The success of this program was made possible through the full support of the Directorate of Research and Community Service (DPPM) of the Ministry of Higher Education, Science, and Technology (Kemdiktisaintek), which provided funding to realize the vision of technology-based learning transformation in schools. Additional support from the Institute for Research and Community Service (LP2M) of Universitas Negeri Makassar (UNM), along with strategic collaboration with SMA Negeri 3 Takalar, further strengthened the implementation of this program.

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