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JR EDUCATION

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International Journal of Information Technology and Education (IJITE) 5 (1), (December 2025) 208 - 244

International Journal of Information Technology and Education (IJITE)

http://ijite.jredu.id

Implementation of Digital Spatial-Based Educational Model Innovation in High Schools in the Islands of North Sulawesi Province

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ARTICLE INFO
Article history:
Received: November 06, 2025; Received in revised form: November 30, 2025; Accepted: December 06, 2025;
Available online: December 07, 2025;

ABSTRACT

The gap in education quality and access in island and border regions remains a structural problem in the Indonesian education system. Fragmented geographical conditions, limited infrastructure, and uneven distribution of educational resources demand innovative, contextual and adaptive educational models. This study aims to analyze the implementation of innovative spatial digital education models in Senior High Schools (SMA) in the Sangihe Islands Regency, North Sulawesi Province. Specifically, this study examines the readiness of spatial digital technology infrastructure, the implementation of spatial digital technology-based curriculum, the impact of these innovations on student achievement, local government policy support, and factors influencing their implementation. This study uses a qualitative descriptive approach with a prospective case study design. Data were collected through field observations, in-depth interviews, and documentation studies involving policy stakeholders, principals, teachers, and students. Data analysis was conducted using an interactive analysis model that includes data reduction, data presentation, and conclusion drawing. The results indicate that the implementation of spatial digital education in Sangihe Islands Senior High Schools is still in its early stages, characterized by limited network infrastructure, suboptimal utilization of geospatial applications in learning, and variations in teachers' digital literacy competencies. However, regional policy support and human resource potential indicate significant opportunities for the development of sustainable spatial digital education models. This research confirms that integrating digital and spatial

approaches can be an alternative strategy for improving access, relevance, and quality of education in archipelagic and border regions.

Keywords: archipelagic regions, border regions, educational innovation, educational management, Sangihe Islands Senior High School, spatial digital education.

INTRODUCTION

Indonesia is a vast archipelagic country. The total area of Indonesia reaches 5,193,250 km². Most of Indonesia's territory consists of water, while its land area covers 1,919,440 km². There are more than 500 districts/cities spread throughout Indonesia. Law Number 20 of 2003 concerning the National Education System states that education is a conscious and planned effort to create a learning atmosphere and learning process so that students can actively develop their potential. The goal of this education is for students to have spiritual religious strength, self-control, personality, intelligence, noble morals, and the skills needed for themselves, society, the nation, and the state. (Hardiasanti & Trihantoyo, 2021). Article 5 paragraph (1) of Law Number 20 of 2003 concerning the National Education System states that every citizen has the same right to receive a quality education. Furthermore, Article 11 paragraph (1) also emphasizes that the Central Government and Regional Governments are obligated to provide services and facilities, as well as to guarantee the provision of quality education for every citizen without discrimination. According to (Valente, 2019), the current educational situation in Indonesia still faces disparities in the quality of education between regions. Schools in rural areas or on the borders have lower quality and fewer enrollments than schools in urban centers. This statement is supported by (Syafii, 2018), who stated that education on the island of Java is better than in areas outside Java. This is due to the focus of national development, which has so far been concentrated solely on the island of Java and because Java is the center of the nation's capital. There is still a lack of equality in the quality of education, especially in regions categorized as outermost, remote, and disadvantaged (3T).

3T regions refer to the Remote, Remote, and Remote Regions. These regions in Indonesia have geographical, social, economic, and cultural conditions that are less developed compared to other regions at the national level. Furthermore, the 3T regions also serve as Indonesia's border gateways with neighboring countries. The 3T regions, which comprise the outermost, most remote, and least developed regions, face significant challenges in development and improving public welfare. One major challenge is poor accessibility. These regions are remote, often far from provincial capitals or government centers, face difficult or dangerous terrain, and lack adequate transportation facilities. This situation results in high logistics costs, difficulties in distributing goods and services, and limited community mobility.

The Ministry of Education and Culture (2012) explains several problems in the implementation of education, especially in the outermost, most remote, and disadvantaged (3T) regions. These include teacher shortages, unbalanced distribution, under-qualification, low competencies, and mismatch between educational qualifications and the field being taught. Another problem in the implementation of education is the relatively high school dropout rate, while school participation rates remain low. In the health sector, 3T regions face serious problems. High maternal and child mortality rates, the

prevalence of malnutrition, and high levels of infectious and non-communicable diseases indicate poor public health conditions. Contributing factors include the lack of adequate health facilities, qualified health workers, and public awareness of health issues. Environmental factors such as sanitation, access to clean water, and pollution also affect health conditions in these regions. Finally, the problems of poverty and social inequality are very real in 3T regions. Low per capita income, slow economic growth, and a low human development index are key indicators. Lack of access to capital, markets, technology, and information is also a major obstacle to the development of micro, small, and medium enterprises. As a result, many residents of the 3T (United Nations) regions live below the poverty line and experience significant social inequality.

Education quality is reflected in the Gross Enrollment Rate (GER), which is the number of people currently attending school at a given level of education compared to the school-age population corresponding to that level. Educational development programs designed to expand opportunities for the population to obtain formal education can be measured using the GER. The GER at the elementary school/Islamic elementary school/Package A level tended to be stable or experienced a small increase from 2022 to 2023. The province with the highest GER at this level was East Nusa Tenggara, with a value of 113.36 in 2022 and a slight decrease to 111.35 in 2023. Papua, on the other hand, showed the lowest GER, particularly in 2023, with a value of 91.1. At the junior high school/Islamic junior high school/Package B level, there was more significant variation between provinces. In 2023, Bali showed a significant increase with the GER reaching 98.18, up from 96.23 in 2022. Conversely, Papua again showed the lowest value, dropping from 83.51 in 2022 to 81.91 in 2023. At the SM/SMK/Package C level, there was a general increase in GER from 2022 to 2023. Several provinces such as North Sumatra and East Kalimantan showed consistent increases. North Sumatra increased from 97.23 in 2022 to 98.02 in 2023, while East Kalimantan increased from 95.09 to 95.16. However, Papua again recorded the lowest value at this level, with a decrease from 77.06 in 2022 to 73.9 in 2023. Overall, it shows that there are significant differences in GER across various education levels and between provinces in Indonesia. Certain provinces, such as East Nusa Tenggara and Bali, show relatively high and stable figures, while Papua consistently ranks among the lowest in APK across all education levels. This data is important as an indicator of access to and participation in education across Indonesia.

Based on the March 2022 Socio-Economic Survey (Susenas), the percentage of North Sulawesi's population aged 7-24 years who are still in school is 69.06 percent, while those who are no longer in school are 30.67 percent. Susenas data also indicates that 0.28 percent of the population aged 7-24 years are not/have not yet received education. To measure the proportion of children who attend school at the ideal age for entering a certain level of education, the Net Participation Rate (APM) indicator can be seen. The APM shows how many school-age residents have utilized educational facilities appropriate to their age and level of education. North Sulawesi's 2022 APM for elementary school/Islamic elementary school (SD/MI) was 95.44, junior high school/Islamic junior high school (SMP/MTs) was 76.11, and senior high school/vocational high school/Islamic senior high school (SMA/SMK/MA) was 63.30. In 2022, the enrollment rate for elementary school (SD/MI/Package A) in North Sulawesi was 106.48, which decreased slightly to 105.41 in 2023. This indicates a small decrease in the number of students entering elementary school (SD/MI/Package A) in North Sulawesi. For junior high school (SMP/MTs/Package B), the enrollment rate increased from 89.63 in 2022 to 90.12 in 2023, indicating a small increase in the participation rate at the junior high school (SMP/MTs/Package B).

Meanwhile, the enrollment rate for junior high school (SMK/SMK/Package C) remained stable at 86.03 for both years. South Minahasa and North Bolaang Mongondow regencies stood out with the highest enrollment rates, at 115.25 and 119.67, respectively. On the other hand, several cities, such as Kotamobagu City, had lower enrollment rates, but were still close to 100%. At the junior high school level, Tomohon City recorded the highest GER with 107.88, while South Minahasa had the lowest GER with 74.06. This indicates significant variation in junior high school participation across regions. At the senior high school level, East Bolaang Mongondow and North Bolaang Mongondow had the highest GERs, at 97.14 and 95.19, respectively. Meanwhile, Bolaang Mongondow recorded the lowest GER with 72.28. Interestingly, most regions recorded quite high GERs at the senior high school level, indicating high levels of senior high school participation. Overall, this shows significant variation in educational participation across levels and regions in North Sulawesi Province. Some regions have very high GERs, indicating more than adequate educational participation, while others are still struggling to achieve more equitable participation.

This is particularly true for the Sangihe Islands Regency, which is one of the border regions between Indonesia and the Philippines. Border regions are often associated with challenges in communication and transportation access, clean water availability, and other issues, including those related to education. Educational issues in this border region are always related to infrastructure and educational staff. A lack of competent teachers, or a preponderance of teachers whose educational qualifications do not match their field of study, results in conventional learning patterns, with teachers simply lecturing without any innovation or modification of the learning system that would further develop students' potential and foster creativity. Based on available data, educational facilities in the Sangihe Islands Regency only include three universities, 27 senior high schools (SMA), 63 junior high schools (SMP), 209 elementary schools (SD), and 91 kindergartens (TK). This reflects the current comprehensive and multi-level educational structure. The presence of three universities demonstrates efforts to provide higher education that can support the development of local human resources and offer opportunities for further study without having to leave the region. The relatively small number of senior high schools compared to junior high and elementary schools indicates a decline in educational facilities as education levels increase, a phenomenon quite common in many regions. This indicates a gap between primary and secondary education levels and higher education. Meanwhile, the very high number of elementary schools indicates a strong focus on basic education, which is crucial for laying the foundation for literacy and numeracy. The availability of 91 kindergartens demonstrates an awareness of the importance of early childhood education in character building and children's readiness to learn. However, this number may still be insufficient to meet the needs of the entire population in the Sangihe Islands Regency, given the importance of early childhood education as the initial foundation for learning.

According to data from the North Sulawesi Central Statistics Agency (2023), the Sangihe Islands Regency demonstrated excellent performance at the elementary school level, with a GER of 113.98, the highest among all registered regencies/cities. This figure indicates a very high number of elementary school-aged children enrolled, exceeding the total number of elementary school-aged children in the region. This could indicate the success of the basic education program and the potential migration of students from other regions. At the junior high school level, the Sangihe Islands also had a high GER of 102.20, indicating that almost all junior high school-aged children were participating in

education. However, there was a significant decline at the senior high school level, with a GER of 78.09. This decline may be due to various factors, such as lack of access to high school, economic conditions, or a lack of awareness of the importance of further education. Meanwhile, education in the Sangihe Islands Regency is directly managed and is the responsibility of the Regency for all matters related to education, from formulating technical policies and developing work plans, to coordinating, financing, and controlling government affairs and providing educational services. Several specific models and initiatives, such as the "boat class" and "prison class" models, have been introduced to address educational challenges and reduce dropout rates, particularly in the context of the COVID-19 pandemic (Wiryanto, 2022). Furthermore, there is a focus on strengthening the implementation of character education in border regions, encompassing aspects such as classroom-based, cultural-based, and community-based character education (Saryono & Daniati, 2017). These efforts aim to improve the quality of education and promote equal opportunities for students in remote and border areas. Innovation in educational models based on digital and spatial approaches is one effort to address the challenges of implementing education in island and border areas. Digital approaches can be utilized to overcome limitations of distance and infrastructure, while spatial approaches can be utilized to accommodate diverse local social and cultural conditions. While many schools have seen sustained improvements in educational practices and student learning outcomes, many schools have also experienced unsuccessful implementation of educational innovations (Datnow, 2002). Some theories of change address these differences in responses to innovation from a unidimensional perspective, such as leadership, professional development, or innovation strategy. Researchers such as Coburn, 2003; März & Kelchtermans, 2013; Werkman et al., 2005 believe there is a need in the field of educational innovation and school development to develop theories about the complexity of innovation processes over time.

Educational innovation, directly or indirectly, aims to improve student academic achievement. From school effectiveness research, we know that teacher professionalism and, more importantly, the quality of instructional processes play a crucial role in student achievement (Diseth et al., 2012; Scheerens, 2011). Furthermore, many researchers have argued in recent decades that educational innovation needs to be examined from multiple perspectives and through the use of complex, multi-level models (Hallinger & Heck, 2011; Scheerens, 2011, 2013; Werkman et al., 2005). One such demand or challenge is the inclusion and use of digital technology in schools. Although digital technology is implemented in education and teaching, various reports from authorities in Sweden state that the use of digital technology for education is still limited and very scattered (Lund, 2012; Thullberg & Millstam, 2010).

This research focuses on the implementation of innovative digital spatial education models in senior high schools in the Sangihe Islands Regency, North Sulawesi Province, with the primary target being senior high schools in the Sangihe Islands Regency. The objectives of this research are as follows:

1) To analyze and describe the readiness of digital spatial technology infrastructure in senior high schools in the Sangihe Islands Regency, North Sulawesi Province.
2) To analyze and describe the implementation of the curriculum through digital spatial technology applications in senior high schools in the Sangihe Islands Regency, North Sulawesi Province.

3) To analyze and describe the influence of digital spatial education innovations on student achievement in senior high schools in the Sangihe Islands Regency, North Sulawesi Province.
4) To analyze and describe the policy support of the North Sulawesi Provincial Government for the implementation of innovative digital spatial education models in the Sangihe Islands Regency, North Sulawesi Province.
5) To analyze and describe the factors influencing the implementation of innovative digital spatial education models in the Sangihe Islands Regency, North Sulawesi Province.

LITERATUR REVIEW

Research conducted by Aylin A'ing (2015) entitled Study on Development of Education Sector in Border Area of Kayan Hulu District, Malinau Regency. This study aims to determine the development of education in border areas, describe the development of education in border areas. This type of research is qualitative descriptive research with sources and key informants Head of BAPPEDA Malinau Regency, Head of Education Office of Malinau Regency and informants from Kayan Hulu Sub-district, School Teachers, Community Leaders, and Kayan Hulu Community. This research was conducted in Kayan Hulu District, Malinau Regency with data collection techniques namely through interviews, observation, documentation, and library research using interactive model data analysis techniques. Based on the results of the study showed that development in the field of education in the border area of Kayan Hulu District experienced a shortage of teachers in several schools in the placement of teachers in each school is still uneven. from the recruitment of teaching staff the system used is teachers take the CPNS test, for contract workers take the test conducted by the Education Office while for honorary workers directly submit a job application to the target school. In the development of educational facilities and infrastructure, many schools still lack adequate facilities such as libraries, teacher housing, and school buildings. Operational assistance for schools is often inadequately supported by guidance and training on proper and effective management. The amount of assistance provided is insufficient to meet all the needs of schools in border areas due to the remoteness of the area.

A study by Adlim, Helida Gusti, and Zulfadli (2016) titled "Educational Problems and Solutions in Island Regions (Case Study of SMA Negeri 1 Pulau Aceh, Aceh Besar Regency) examined educational problems and alternative solutions in high schools in remote, small-island areas. This school is located in a small village on Pulau Nasi Island, approximately one hour by small boat from the nation's capital, Banda Aceh, Indonesia. Data were collected through structured interviews, questionnaires, direct observation, and focus group discussions (FGDs). Respondents were the principal, teachers, students, community representatives, and the Head of the Regency Education Office. The study found that the school in question received a C grade according to national education standards and had the lowest national exam scores among high schools in the district. The majority of teachers (60%) do not live on the remote island, resulting in the curriculum not being implemented. The majority of respondents stated that teachers were often absent from class because they could not get to the island due to bad weather (high sea waves) and other reasons. They came to school only during teaching hours and then returned to the mainland, severely limiting their interaction with students. The characteristics of teachers who lived on the island were those who were married or had relatives with local residents,

and those who were on temporary contracts who had applied for permanent government positions. The majority of teachers who already had permanent employment lived on the mainland (in the city) and preferred the risk of sailing to the island every week rather than living in the village. This phenomenon did not occur on the larger island (Simeulue), the regency capital, which has city facilities. To address these problems, the majority of respondents suggested several alternative solutions, including improving school management, such as recruiting new contract teachers to replace current teachers who were unwilling to live on the small island. The regional Education Office was also urged to consistently implement education regulations.

Research conducted by Putu Indra Christiawan (2014) entitled Innovation in Disaster Education Based on Spatial Approach in Indonesia. This research aims to dissect the correlation between educational backwardness in Indonesia and the increase in disaster incidents through understanding and analysis of: (1) the essence of disaster education, 2) the orientation of spatial intelligence in education and (3) the implementation of spatial education as an innovation in disaster education based on the results of theoretical and empirical studies of the condition of education in Indonesia. The results of the discussion in this paper indicate that: (1) education is one of the main social vulnerability factors that has a large contribution to the occurrence of a disaster, so it is considered important to have education that emphasizes spatial intelligence so that students have the ability to understand the conditions or characteristics of diverse spaces, (2) spatial intelligence in education has an orientation to be able to understand and solve many cases in everyday life as well as problems in the local, regional, national and global scope; to be able to collaborate with many disciplines; for the development and advancement of new technologies and the ability to understand the processes of human, environmental, and societal interactions, as well as achieving geoliteracy. (3) educational innovations that must be used in schools, particularly in disaster-prone areas and generally in Indonesia, related to disaster mitigation efforts, include a spatial approach. The spatial approach is used to understand geospheric phenomena in order to develop knowledge.

Research conducted by Kusnandar (2013) entitled "Developing a Model for Utilizing Information and Communication Technology (ICT) for Education in Remote, Underdeveloped, and Frontier Areas" describes the development of a model for utilizing information and communication technology for schools in remote, underdeveloped, and frontier areas. The model is implemented in the form of "PSB in the 3T Regions," namely information and communication technology-based learning resource centers in schools in remote, underdeveloped, and frontier areas. The development is based on the concepts of modern learning, empowerment, bottom-up growth, and partnerships, as well as learning from the experiences of other countries. The pilot was developed in five regions: Naringgul, Cianjur (West Java), Cijaku, Lebak (Banten), Atambua, Belu (NTT), Sebatik, Nunukan (East Kalimantan), and Marore, Sangihe Islands (North Sulawesi). In each of these regions, one elementary school and one junior high school were selected that lacked electricity and internet access. Each school was provided with a complete learning resource center assistance package consisting of a solar power generator, satellite dish, television, six laptops, a modem, Wi-Fi, and a one-terabyte hard disk containing digital learning materials. To ensure the success of this program, training and guidance packages, mentoring, monitoring, and studies were also provided. Furthermore, it is hoped that this program can be implemented independently by each school. This model can be adopted or adapted by the Department of Education in order to provide services to improve the quality of learning in their respective regions.

A study conducted by Arie Kurniawan and Sudirman Siahaan (2015) entitled Towards Integrated ICT Learning on Marore Island, the Border between Indonesia and the Philippines. This study discusses efforts towards integrated ICT learning for learning at SDN Marore and SMPN 3 Tabukan Utara, Marore Island, Sangihe Regency, North Sulawesi. These two schools are included in the 3T (frontier, disadvantaged, and remote) area category. The determination of schools and areas was carried out through a feasibility study. These two schools are not only equipped with the Center for Educational Information and Communication Technology (Pustekkom) with ICT facilities/devices, various digital learning resources, but also teachers and technicians are trained in the operation and maintenance of ICT devices, design and development of learning materials. This paper aims to examine various efforts towards integrated ICT learning. To achieve this goal, the authors used interview guidelines and questionnaires and conducted focus group discussions (FGDs) and the results are presented descriptively. Respondents stated that the introduction of integrated ICT learning is very beneficial for efforts to improve the quality of learning. Therefore, it is recommended that ongoing and intensive training be conducted not only on designing and developing digital learning materials but also on implementing strategies for integrated ICT learning.

This research was conducted by Very Londa (2016) entitled "Implementation of Basic Education Policy in the Islands Region (A Study in the Sangihe Islands Regency, North Sulawesi Province"). The Sangihe Islands Regency, with 20,209 school-age residents, or 24.38% of the population, faces challenges including a lack of teachers willing to be placed locally; a lack of physical facilities, including buildings, teaching aids, laboratory equipment, textbooks, and other student supplies; and incomplete educational data to support the online Jardiknas program. This study aims to explain the implementation process of basic education policy in the development of public administration science and address basic education issues in the Sangihe Islands Regency. Through a qualitative design, this study found that although the implementation of basic education policy in the Sangihe Islands Regency is limited in terms of idealized policy, implementing organization, and environmental factors, particularly the political institutional environment, it has been successful in increasing average subject scores. There has also been an increase in graduates and other achievements achieved by students in various competitions, both at the regional, provincial, and national levels. This situation is considered unique by researchers, where educational achievement increases despite limited funding, in underdeveloped and border areas.

Innovation in educational models in island and border regions, particularly in North Sulawesi Province, is a crucial need within the context of regional development. This framework begins with an understanding of the unique challenges faced by island and border regions, such as limited physical access, resources, and disparities in educational infrastructure. Amidst these conditions, integrating digital and spatial approaches into the education system offers an innovative solution. The use of digital technologies, such as online learning, educational applications, and interactive platforms, can open broader and more flexible access to education. Meanwhile, a spatial approach, which includes geographic mapping and local context analysis, will support the development of educational content that is relevant and tailored to the specific needs of island and border regions.

This framework also incorporates the concept of inclusive regional development policies, in which the North Sulawesi Provincial Government can play a key role in coordinating resources, establishing policies, and overseeing the implementation of educational programs. This is crucial to

ensure that educational innovations are not merely theoretical but also practical and have a direct impact on improving the quality of education in island and border regions. Furthermore, this framework also explores the potential for collaboration between the government, educational institutions, local communities, and other stakeholders to produce effective synergies in realizing the vision of advanced and inclusive education in North Sulawesi Province.

METHOD

Research Type

This research uses a "descriptive qualitative" case study approach. The case study approach used in this research is a prospective case study. This type of case study is necessary to identify trends and development directions in a case (Suwardi, 2003). In this context, the research explores how digital technology and spatial analysis can be utilized to address the unique challenges faced by education systems in island and border regions. These regions often experience constraints such as limited physical access, limited resources, and geographic isolation. The use of digital technologies, such as online learning and web-based educational resources, can be an important solution to overcome these obstacles. Furthermore, a spatial approach, involving geographic mapping and analysis, can be used to better understand the distribution of educational resources and community needs in these regions.

This combination of digital and spatial approaches enables researchers and policymakers to design and implement more effective and efficient solutions, taking into account the unique characteristics of island and border regions. The resulting educational model can improve the quality and availability of education in these regions, which in turn can help accelerate development and economic growth in North Sulawesi Province.

Place and Time of Research

The research will be conducted in the Sangihe Islands Regency, with the primary target schools being SMA Negeri Pintareng, SMK Negeri Tabukan Utara, SMK Muhammadiyah Naha, SMA Negeri I Tahuna, SMA Petra Sawang Jauh, and SMA Negeri I Tatoareng.
The research period is 12 (twelve) months, and will be conducted from June 2024 to May 2025.

Population and Sample

The population in this study is all individuals or elements related to educational model innovation in island and border areas based on digital and spatial approaches in North Sulawesi Province. This includes:

1) Policymakers: Provincial and Regency Education Offices.
2) Implementers of Education and Infrastructure Policy: Provincial Education Office Technical Implementation Units, Head of Public Works and Spatial Planning Office.
3) Policy Implementers at the Operational and National Border Level: This includes the Border Management Agency and Border Sections.
4) Stakeholders in Schools: Principals, Teachers, and Students.

A sample is a portion of a population selected to be representative in a study. In this context, samples can be drawn from each population category:

1) Education Policymakers: Provincial and Regency Education Offices.
2) Education and Infrastructure Policy Implementers: Heads of Public Works and Spatial Planning Offices from the same district as the policymakers.
3) Policy Implementers at the Operational and National Border Levels: Provincial and Regency Border Management Agencies.
4) High School Stakeholders: Several principals and teachers from schools in island and border areas, as well as randomly selected students.

Data Collection Techniques

Observation.

This data collection technique is used to gather the necessary data to complement the data from interviews. Observations are conducted to obtain information about the research object by observing and recording events or situations (Sulistyo-Basuki, 2006). Observation is an observational activity conducted by the researcher, where the researcher plays an active role in the study location, thus truly observing the activities being studied. In this observation, the researcher is involved in the daily activities of the people being observed or used as data sources for the study. This observation technique is used to obtain data on the steps taken in thematic learning. Observations are conducted by actively going directly into the field to obtain real-world descriptions and information regarding the attitudes and behaviors of informants.

Interviews

Interviews are a data collection process that directly obtains information from the source. Interviews are a process of interaction and communication. The results of interviews are determined by several factors, namely the interviewee, the informant, the topic outlined in the questionnaire, and the interview situation (Singarimbun, 2008). An interview is a conversation between two people with a specific purpose. These two people are the interviewer and the interviewee, who will provide answers to the questions (Moleong, 2010). Interviews are conducted to obtain information from respondents. The author used in-depth interviews. This type of interview is similar to a discussion with a subject. The goal is to gather diverse information, mostly containing opinions, attitudes, and felt experiences.

*Documentatio*n

Documentation is data collection processed through documents. The documentation method is used to collect data from documented sources that may support or even contradict the interview results. This technique is used to obtain data in the form of documents or archives. The documentation method is implemented to complement the data obtained from interviews and observations. The data obtained can be in the form of written texts and recordings such as manuals, official reports, diaries, and meeting minutes. Triangulation is a data validity checking technique that utilizes something other than the data itself for checking or comparing the data (Moleong, 2009). To ensure continuity and facilitate research, due to limited time, energy, and resources, the study will use a population and sample to determine the research objectives.

The following data sources are considered primary data and secondary data:

1) Primary data: The Department of Education, the Department of Public Works and Spatial Planning, the Border Management Agency, school principals, teachers, and students (selected at random).
2) Secondary data: Written data in the form of books, reports, and charts obtained from the Regional Development Planning Agency (BAPPEDA), the Department of Education, the Department of Public Works and Spatial Planning, and the local district border management agency. Basic Education Data (DAPODIK) from the North Sulawesi Provincial Education Office, and Spatial Map Data on the Distribution of Educational Facilities in the Sangihe Islands Regency.

Data Analysis Techniques

The data analysis technique used in this study refers to the concept (Miles et al., 2014), namely the interactive model, which classifies data analysis into three steps:

Data Reduction

From the writing location, field data is presented in a complete and detailed report description. The data and field reports are then reduced, summarized, and sorted into key points, focusing on selecting the most important ones, and then searching for themes or patterns (through editing, coding, and tabulating). Data reduction is carried out continuously throughout the writing process. At this stage, after the data has been sorted and simplified, unnecessary data is sorted to facilitate display and presentation, and to draw preliminary conclusions.

Data Display

Data display is intended to make it easier for the writer to see the overall picture or specific parts of the written data. The data presentation used in this step is in the form of a narrative text of the research results.

Drawing Conclusions (Verification)

The researcher attempts to draw conclusions and verify them by seeking meaning in the phenomena observed in the field. They note possible regularities and configurations, as well as causal flows of phenomena and propositions.

At this stage, the conclusions previously drawn and concluded are drawn. The author then rechecks and compares them with the results and notes collected during the research. Ultimately, the expected outcomes of this research will be research results and articles for international publication. This research will address issues such as limited access to education in island and border areas, limited technological infrastructure, teacher readiness and capabilities, relevant educational content, cultural and social considerations, government funding and support, community and stakeholder involvement, monitoring and evaluation, student readiness, continuity and sustainability, with breakthroughs in the form of digital and spatial approaches as an innovative educational model in island and border areas, contributing to the planning of regional development policies for North Sulawesi Province.

RESULTS AND DISCUSSION

Readiness of Spatial Digital Technology Infrastructure in the Sangihe Islands Regency, North Sulawesi Province.

Based on the results of interviews in the field, a number of data were obtained from informants from the Provincial PUPR Service that since 2021, only 9 out of 15 sub-districts (60% of sub-districts) have had Base Transceiver Station (BTS) infrastructure.

"*Only 60% or 9 sub-districts have received BTS infrastructure since 2020 with funding from the Central Government" (CL-WD1I-1).*

This data indicates that the readiness of spatial digital technology infrastructure is not yet optimal. This is due to a number of sub-districts experiencing a digital access gap, resulting in a lack of optimal implementation. This data is also supported by informants who stated that the availability of this infrastructure only began in 2021.

"starting availability in 2021" (CL-WD1I-2)

"There is still a gap in digital access between sub-districts as well as a gap between availability and utilization"(CL-WD1I-6)

The results of the interview found that supporting regulations related to digital spatial already exist through the Regional Regulation of North Sulawesi Province No. 1 of 2025 concerning the 2025-2029 RPJMD and the Regional Regulation of Sangihe Islands Regency No. 3 of 2025 concerning the 2025-2029 RPJMD of Sangihe Islands Regency.

"*Contained in the provincial and district RPJMD regulations*" (CL-WD1I-4)

Based on field research findings, only 9 of the 15 sub-districts in the Sangihe Islands Regency, or approximately 60% of high schools (SMA), have technological infrastructure, such as base stations (BTS) and internet networks (2021-2024), which are the initial foundation for developing digital spatial education. Although their utilization is not yet fully optimized and still faces various limitations, such as inadequate internet speed. In terms of network infrastructure and connectivity, some high schools (SMA) located in sub-district centers and areas relatively easily accessible from the regency capital have good internet access, either through cellular networks or satellite-based internet services. This access enables the use of digital learning resources, online map applications, and technology-based learning platforms such as GIS, although network quality remains fluctuating and uneven across islands.

Regarding hardware, research findings indicate that a number of high schools (SMA) also have digital learning support devices, such as desktop computers, laptops, LCD projectors, and presentation equipment. These devices are generally obtained through government assistance programs, such as the procurement of school Information and Communication Technology (ICT) and the utilization of educational operational assistance funds. This hardware infrastructure certainly serves as the initial capital in introducing digital map-based learning and spatial visualization. From the software and digital spatial application aspects, research findings indicate that all senior high schools (SMA) have not utilized Geographic Information System (GIS) applications, digital maps, satellite imagery, Global Positioning System (GPS), and web-based digital mapping platforms as contextual learning media. Although digital spatial applications of these geospatial information system software do not yet exist, they have shown the potential for developing more systematic digital spatial education in the future. Although digital spatial applications are not yet available through open access to base maps such as

thematic maps of administrative areas, the future development of digital spatial education can be integrated into the learning systems of all senior high schools, because they can later be used as contextual teaching materials relevant to the characteristics of the Sangihe Islands region. In terms of human resources, there are teachers who already have basic digital literacy and experience using technology-based learning media. Research findings show that the presence of teachers with initial competencies is a very important non-physical infrastructure in supporting the development of spatial digital education in the future.

Thus, the digital spatial technology infrastructure available in all senior high schools (SMA) in the Sangihe Islands Regency is currently still at a very basic stage, with only hardware network infrastructure, simple digital spatial applications, and teachers' initial digital knowledge competencies. All of this forms the initial foundation for the implementation of digital spatial education. Further strengthening and development are essential to ensure optimal and sustainable utilization of the existing infrastructure.

Several studies have shown that remote and 3T (frontier, outermost, and disadvantaged) areas in Indonesia still face serious limitations in digital infrastructure, directly impacting their readiness to adopt educational technology. These 3T areas often experience unstable internet access, limited technological devices, and inadequate electricity, creating barriers to the use of technology in educational settings. This is further reinforced by research showing that technology access in 3T areas lags significantly behind that of urban areas, due to various factors such as physical limitations in network access and device access. This inequality creates challenges in equalizing the quality of digital education, including the potential implementation of geospatial technology in schools (Farhatin, F., 2025). Internet access is also a key component of digital infrastructure, influencing spatial technology readiness. GIS-based research based on spatial analysis in Indonesia emphasizes the need to map internet needs that considers geographic conditions to prioritize connectivity infrastructure development. This uneven quality of access is often related to differences between regions, with rural and island areas still experiencing disparities in telecommunications infrastructure and digital networks (Widjaja et al., 2025).

The 2025-2029 National Medium-Term Development Plan document outlines the Indonesian government's plans to expand this access, including network expansion through a program to build base transceiver stations (BTS) and digital connectivity in the 3T (frontier and remote) regions, as well as low-cost internet subscriptions aimed at opening up wider internet access opportunities for remote communities and supporting various digital services, including modern education. This is crucial because without adequate network access, digital technology—including geospatial applications that require data connectivity—cannot be effectively operated at the school or community level. Technological infrastructure encompasses not only internet connectivity but also the availability of digital devices, a stable electricity system, and human resources capable of operating the technology. Research on the use of ICT for education in remote areas emphasizes the principles of empowerment, sustainability, a bottom-up approach, and partnerships to improve the quality of learning through technological support. Areas with limited access to technology tend to experience obstacles in improving the quality of learning and student and teacher motivation (Warsihna, 2013).

Furthermore, digital literacy and technology user readiness are also part of broader infrastructure readiness. Widiasanti (2025) found that unequal access to devices and networks not only impacts

students' ability to engage in digital learning but also teachers' ability to utilize technology for innovative learning practices. Spatial digital technology—which includes GIS-based mapping and other geospatial applications—requires stable infrastructure that involves not only internet access but also compatible software and competent human resources for the operation and maintenance of spatial data. These three infrastructure dimensions are interrelated and are prerequisites for spatial digital readiness in regions such as the Sangihe Islands Regency. Infrastructure limitations in remote areas reflect common challenges in the 3T (Underdeveloped, 3T) regions (Farhatin, 2025). This can serve as a foundation for understanding strategic needs in the context of the Sangihe Islands Regency.

Implementation of Spatial Digital Technology Curriculum in High Schools in Sangihe Islands Regency, North Sulawesi Province

Based on the results of interviews in the field, a number of data were obtained from informants from the Principal and Teachers that the school had implemented digital spatial-based learning through the application of the school curriculum as part of digital simulation learning, Informatics and Computer Engineering and Networks.

"Vocational Schools have implemented KTSP, K-13, Merdeka Mer Curriculum, and In-depth Learning Curriculum since its implementation" (WK3II-1)

"Through the learning process of Digital Simulation, Informatics, Computer Engineering & Networks [TKJ]" (WK3II-2)

This is supported by informants from school principals and teachers who stated that the implementation of digital spatial learning in schools is carried out through the National Curriculum, adapted to the school's specific needs. The current National Curriculum uses the Merdeka Curriculum with an in-depth learning approach.

"*The National Curriculum is adapted to the school context*" (WK2II-3)

"*The curriculum at our school uses an independent curriculum with an in-depth learning approach" (WG1II-5).*

In interviews with informants from school principals and teachers, it was stated that the implementation of digital spatial learning started in various ways between schools, ranging from 2020 to 2021, but some only started in 2025. The implementation is integrated with digital technology regulations related to the applicable curriculum.

"Implemented since 2020"(WK2II-4)

"Since the implementation of digital-based learning regulations in Indonesia, it includes various regulations. An example is Permendikdasmen No. 13 of 2025 which integrates digital technology into the curriculum" (WK3II-4)

"Implemented since the beginning of 2025-2026" (WK5II-4)

"Implemented since 2021" (WG1II-4)

This data is supported by interviews with the principal and teachers who explained that the output of this curriculum has a significant impact on students' skills in mastering learning, students' ability to relate the knowledge gained to real life so that learning outcomes are more meaningful for students.

"Mastery of Learning Outcomes, Ability to relate theory to real life, formation of noble values in the profile of Pancasila students" (WK2II-5)

“"Making graduates think faster, more precisely and more efficiently" (WK4II-5)

“Better learning outcomes” (WG1II-6)

Similarly, interviews with principals and teachers revealed that the number of dedicated digital spatial teachers varies from school to school. Some schools already have dedicated teachers, while others do not.

“ *Yes. We have a special teacher for this material” (WK3II -6)*

“ *There is no special teacher”* (WK4II-6)

“Informatics Teacher” (WG1II-6)

“Yes, there are teachers who actually teach the ICT department” (WG1II-6)

Based on the results of interviews in the field, data was obtained that until now there has been no special training for teachers regarding digital spatial learning.

“There is no special training yet”(WL1II-7)

Based on field research findings, several senior high schools in the Sangihe Islands Regency have not yet implemented a digital spatial technology curriculum into their learning systems. This is because: nationally, Indonesia has not yet positioned this digital spatial curriculum as a core or primary competency. In the independent curriculum, digital spatial competency is still implicit, meaning this subject is only integrated into the subjects of geography, informatics, and the Pancasila Student Profile Strengthening Project (P5). Digital spatial subjects have not yet been specifically designated as a special subject like geotechnology or GIS/GIS in senior high schools. Therefore, the implementation of digital spatial subjects still relies heavily on the initiative of schools or teachers, rather than a systemic mandate.

The use of digital spatial technology in learning in senior high schools (SMA) is a pedagogical innovation relevant to the demands of scientific and technological developments and national education policy. Digital spatial includes the use of Geographic Information Systems (GIS/GIS), digital maps, satellite imagery, the Global Positioning System (GPS), and web-based digital mapping platforms that enable interactive visualization, analysis, and interpretation of spatial phenomena. Within the context of the Independent Curriculum, high school learning is directed toward developing 21st-century competencies, including critical thinking, problem-solving, creativity, communication, collaboration, and digital literacy. The use of digital spatial technology aligns with the learning outcomes (CP) for high school Geography, which emphasize understanding the concepts of location, distribution, patterns, human-environmental interactions, and sustainable regional dynamics.

Conceptually, the use of digital spatial technology serves as a means to enhance students' understanding of abstract geographic concepts. Through dynamic spatial visualizations, students can directly observe the distribution of natural and social phenomena, such as population density, land use, natural resource distribution, and disaster potential and risks. This aligns with the principle of meaningful learning emphasized in the Independent Curriculum, where knowledge is built through contextual learning experiences. Furthermore, digital spatial technology plays a crucial role in developing high school students' spatial and critical thinking skills. GIS-based learning activities encourage students to analyze data, interpret maps, compare conditions between regions, and draw conclusions based on empirical evidence. This competency aligns with the demands of Higher Order Thinking Skills (HOTS), which are the assessment orientation in the national curriculum. The use of digital spatial learning can also support the implementation of project-based learning and problem-

based learning, as recommended in the Merdeka curriculum. Through this approach, students can examine real-world issues in their environment, such as floods and landslides, climate change, urbanization, and environmental degradation, using spatial data as the basis for analysis. Thus, learning is not only oriented toward mastery of material but also toward strengthening character, environmental awareness, and decision-making skills.

From a digital literacy perspective, the use of digital spatial technology contributes to strengthening the Pancasila Student Profile, particularly in the dimensions of critical, creative, and independent reasoning. High school students are trained to access, process, and present spatial data-based information responsibly. This competency is an important provision for high school students in facing the challenges of higher education and the world of work in the era of the Industrial Revolution 4.0 and Society 5.0. Furthermore, digital spatial technology enables interdisciplinary learning, as recommended in the Merdeka curriculum. Spatial data and analysis can be integrated with other subjects such as Biology (ecosystems and biodiversity), Economics (industrial and trade areas), History (territorial changes and historical maps), and Sociology (population density and urbanization). This integration enriches students' learning experiences and strengthens interdisciplinary connections between disciplines. Digital spatial technology plays a strategic role in high school learning in Indonesia. The use of this technology not only improves the quality of students' conceptual understanding but also supports the holistic implementation of the Merdeka Curriculum, particularly in the development of 21st-century competencies and the Pancasila Student Profile. Thus, the implementation of a digital spatial technology curriculum in high schools in the Sangihe Islands is expected to produce high school students with critical thinking skills, basic skills, and extensive knowledge of area-based contextual learning.

The implementation of a digital spatial technology curriculum in high schools aims to improve students' understanding of spatial concepts and geographic mapping through the use of digital tools and applications such as Geographic Information Systems (GIS), Google Earth, and simple mapping software. According to Lasulika and Lukum (2025), the integration of geospatial technology in geography learning can bridge theory with real-world practice, enabling students to understand spatial relationships concretely. In the context of the Sangihe Islands, this integration is relevant because students can directly map the local environment, such as coastal conditions, settlement distribution, or natural resource potential, which are in accordance with the characteristics of the islands (Lasulika & Lukum, 2025). The literature emphasizes that the effectiveness of spatial digital technology depends on the pedagogical model used. Project-Based Learning (PBL) and Inquiry-Based Learning approaches have proven effective in improving students' critical thinking and spatial analysis skills (Tusam et al., 2025). In high schools in the Sangihe Islands Regency, this approach allows students to be directly involved in local environmental mapping projects, for example mapping disaster evacuation routes or the distribution of public facilities. This project-based approach helps students connect curriculum concepts with real conditions in the island area, making learning more contextual and meaningful (Tusam et al., 2025).

In addition to the above, technologies such as Google Earth and 3D Mapping in Microsoft Excel can be used for spatial data visualization. Purba, Purwanto, & Wijiyono (2025) demonstrated that spatial visualization can enhance students' understanding of the geographic distribution, spatial patterns, and environmental phenomena around them. This is particularly relevant for Sangihe, which

consists of many islands, as students can visualize spatial conditions between islands without having to physically travel. The use of digital spatial technology in the curriculum has been shown to improve students' spatial thinking skills. Ramadhani, Bakri, & Khairani (2025) found that students who learned using GIS had better spatial analysis skills than students who learned conventionally. These skills include map interpretation, geographic pattern identification, and location-based problem solving. In the context of high schools in the Sangihe Islands, this improved competency has direct implications for students' readiness to face local environmental challenges, such as disaster mitigation and regional planning.

Despite the high potential of digital spatial technology, its implementation faces several challenges in high schools in the Sangihe Islands. First, limited infrastructure, such as unstable internet connections and the availability of computer devices, is a major obstacle. Second, teacher competency in using and integrating digital spatial technology into the curriculum still varies. Widiyatmoko et al. (2024) showed that the adoption rate of GIS technology by geography teachers in remote areas is still moderate, necessitating ongoing training to improve learning effectiveness. Furthermore, students' digital literacy is also a determining factor in success. Inequality in access to devices and internet networks impacts students' ability to optimally utilize digital spatial technology (Journal of Educational Technology and Learning, 2025). Therefore, adaptive strategies that consider local conditions are crucial, such as the use of lightweight software and field-based projects that can be conducted with minimal access.

The implementation of the digital spatial technology curriculum in the Sangihe Islands must adapt to local characteristics. The archipelago presents challenges in terms of limited infrastructure and inter-island access, but also provides opportunities for real-world learning. By integrating local mapping projects into the curriculum, students not only learn theory but also gain hands-on experience in solving spatial problems relevant to their daily lives, such as disaster mitigation, transportation route mapping, and natural resource management. This is in line with the demands of 21st century education which emphasizes critical, creative and contextual thinking skills (Dewi et al., 2025).

The influence of Digital Spatial-Based Educational Innovation on the Learning Achievement of High School Students in Sangihe Islands Regency, North Sulawesi Province

Based on field interviews, data obtained from several student informants indicated that digital spatial learning impacted student achievement, enabling them to better understand the material through engaging visual displays of maps and spatial data, thereby improving their learning outcomes. However, some students stated that digital spatial learning did not have an innovative impact on their academic achievement.

"Yes, because it provides interactive visual materials, access to learning resources is wider" (*WS7III-1)*

"This learning does not affect" (WS8III-1)

"Yes, this digital system has quite an impact on student learning achievement because it facilitates access to learning resources and helps students understand the material through attractive visual displays of maps and spatial data" (WS34III-1)

"Yes, I think the digital spatial system has significantly impacted my academic performance because it makes it easier for me to understand the material, especially those that require images, maps, or visuals. As a result, my grades have also improved" (WS39III-1).

The data related to the innovative influence on digital spatial learning is supported by data from interviews with teacher and student informants who said that a number of student achievements related to digital spatial learning, such as understanding spatial concepts and spatial analysis skills, can improve critical thinking skills and be able to work on digital project-based assignments.

"The achievements produced include increased conceptual understanding, spatial analysis skills, technological skills, and better academic results for students" (WS4III-2)

"The resulting achievements include increased student ability to understand the concepts of space, spatial data, and digital technology, increased critical thinking skills, and better academic achievement in digital project-based assignments" (WS37III-2)

However, in interviews with teacher and student informants, it was found that there were several obstacles encountered in the implementation of digital spatial learning at this time, including limited digital infrastructure, the digital divide between one sub-district and another, limited infrastructure, funding, lack of competent human resources, and limited student access to the internet.

"The digital divide, differences between students in cities and villages, as well as wealthy and poor families and low digital literacy, financing constraints" (WG2III-3)

"Spatial digital systems such as geographic information systems GIS and remote sensing, such as infrastructure and cost limitations, teacher skills and knowledge, resource quality and skills, curriculum integration" (WS6III-3)

"Obstacles to learning may be that some children on remote islands or in rural areas do not have cell phones, and the problem is with the network or they do not have money to buy a data package" (WS31III-3)

"The main obstacles are limited internet networks in some areas, a lack of devices such as laptops or tablets, and there are still students and teachers who are not used to using digital spatial applications" (WS32III-3)

Despite the presence of a number of obstacles obtained from informants, teacher and student informants understand the benefits of this digital spatial learning. Teachers and students mentioned a series of benefits of this digital spatial learning, namely simplifying the learning process for students and teachers by helping them understand the concept of interactive visualization more realistically, training logical and spatial thinking skills, helping students understand the relationship between location, space, and data visually as well as improving analytical skills and facilitating learning geography, regional planning, and environmental-based problem solving. However, it was also found that there were student informants who did not understand the benefits of this digital spatial learning.

"Useful for teachers and students to facilitate the learning process" (WG1III-4)

"Spatial digital learning is useful for visualizing data and information more realistically, helping students understand relationships between spaces, and training critical thinking and technology-based problem-solving skills" (WS4III-4)

"There is no point" (WS14III-4)

"I don't know" (WS28III-4)

"Its use is to help students understand real regional conditions through digital maps, improve spatial analysis skills, and train them in the use of technology that is relevant to future needs"(WS32III-4)

"Spatial digital learning is useful for helping students understand the relationship between location, space, and data visually; improving analytical skills; and facilitating the learning of geography, regional planning, and environmental-based problem-solving" (WS40III-4)

Innovation in digital spatial education will significantly contribute to improving student learning achievement, across cognitive, affective, and skills aspects. Data shows that the integration of digital spatial technologies, such as digital maps, Geographic Information Systems (GIS), and technology-based spatial visualization, can significantly improve the quality of the learning process and student learning outcomes. From a cognitive perspective, digital spatial education helps students understand abstract concepts more concretely and visually. Presenting information in the form of interactive maps and spatial data enables students to develop spatial thinking, analytical skills, and problem-solving skills. Field findings indicate that students involved in digital spatial learning are better able to relate subject matter to real-world conditions, thus positively impacting conceptual understanding and improving academic achievement. In terms of motivation and learning engagement, innovation in digital spatial education encourages increased student interest and active participation in the learning process. The use of interactive digital technology makes learning more engaging and contextual, especially for students in island regions who are directly exposed to spatial phenomena in their daily lives. This increased learning motivation indirectly contributes to student learning achievement. Furthermore, from a 21st-century skills perspective, digital spatial education supports the development of digital literacy, collaboration, and critical thinking skills. Through project-based learning, such as mapping local areas or analyzing coastal environments, students gain not only academic knowledge but also practical skills relevant to future needs. Previous research has shown that students engaged in digital spatial learning demonstrated improved abilities in presenting data, arguing based on evidence, and working collaboratively.

The effectiveness of this innovation is greatly influenced by infrastructure readiness, teacher competence, school support, and the home learning environment. In conditions of limited infrastructure, digital spatial innovation does not fully produce optimal improvements in learning achievement, but rather is more visible in increased student motivation and learning experiences. Digital spatial educational innovation has a positive impact on student achievement through improved conceptual understanding, learning motivation, and the development of spatial thinking skills. This influence is not solely direct, but is mediated by the quality of learning implementation, resource readiness, and support from the educational ecosystem. Therefore, digital spatial educational innovation should be viewed as a strategic approach that has the potential to improve student learning achievement sustainably if supported by adequate policies, infrastructure, and teacher capacity building. Digital spatial-based educational innovation is an effort to integrate geospatial technology into the learning process to improve students' understanding of spatial concepts and applications. This technology includes GIS (Geographic Information System) software, Google Earth, 3D digital mapping, and other spatial data visualization applications. According to Lasulika & Lukum (2025), the implementation of digital spatial technology at the secondary school level can help students connect theoretical concepts with real-world phenomena in their environment, thereby improving conceptual understanding and the relevance of learning.

In the Sangihe Islands Regency, this innovation is highly relevant because the region's multi-island character requires spatial thinking skills and an understanding of geographic distribution, both

in the context of the environment, disaster mitigation, and local resource management. Therefore, digitalizing learning using spatial technology can provide a more contextual and applicable learning experience. Several studies have shown that the use of digital spatial technology has a positive impact on student achievement. Ramadhani, Bakri, & Khairani (2025) found that students who used GIS in geography learning had higher spatial analysis skills and a better understanding of geographic concepts than students who learned using conventional methods. This indicates that digital spatial technology is not only a visualization medium but also an active and interactive learning tool. In addition to GIS, applications such as Google Earth or 3D Mapping have also been shown to improve students' ability to understand spatial relationships, geographic distribution patterns, and environmental phenomena more deeply. Purba, Purwanto, & Wijiyono (2025) emphasized that spatial visualization enables students to explore data, analyze patterns, and solve location-based problems, thereby making the learning process more effective.

In the context of high schools in the Sangihe Islands, this innovation supports learning achievement through:

1) Improving spatial thinking skills – students are able to understand the relationships between islands, the distribution of facilities, and local environmental phenomena.
2) Increasing learning motivation – the use of interactive digital media makes students more interested and engaged in learning.
3) Contextual problem-solving – students learn to analyze spatial data related to real-world situations, such as disaster mitigation or local resource management.

Research by Widiyatmoko et al. (2024) shows that the adoption rate of GIS technology in high schools varies, making teacher training and technical support key factors in maximizing the impact of this innovation on learning achievement. The implementation of digital spatial innovations in the Sangihe Islands Regency can improve the quality of learning and student academic achievement, provided it is supported by adequate infrastructure, sufficient teacher competency, and contextual learning strategies. Project-based learning models that utilize local spatial data are highly relevant to students' needs to understand their environment, while also equipping them with 21st-century skills such as critical thinking, collaboration, and problem-solving. A literature review shows that digital spatial innovation can be an effective means of overcoming the geographical limitations of island regions, as it enables interactive learning that is not entirely dependent on the physical conditions of the location. This aligns with the principles of contextual and authentic learning, enabling students to better apply knowledge in their daily lives.

Policy support from the North Sulawesi Provincial Government in Implementing Digital Spatial-Based Education Model Innovations in the Sangihe Islands Regency, North Sulawesi Province

Based on the results of interviews in the field, data was obtained from informants from the North Sulawesi Provincial Border Management Agency that there is already policy support from the North Sulawesi Provincial Government in implementing innovations in spatial digital-based education models in the Sangihe Islands Regency, namely through cross-sector collaboration in border areas, especially the outermost islands and special location sub-districts for priority basic service programs including education.

"There is collaboration with stakeholders in border areas, especially on the outermost islands and special location sub-districts, to prioritize and prioritize programs to improve basic services, including education" (WL2IV-1)

The data is supported by statements from informants from the North Sulawesi Provincial PUPR Service and the North Sulawesi Provincial Border Management Agency who said that there are policies or activities supporting spatial-based education in the form of Geospatial Information Agency (BIG) network nodes, infrastructure development and internet access, and coordination with related agencies.

"Network node initiated by BIG"(WL1IV-2)

"Development of infrastructure and internet access" (WL2IV-2)

"BPPD with its coordination duties, the role of BPPD is to facilitate and coordinate with related agencies" (WL3IV-2.

Some other spatial-based education support activities are the development of a Base Tranceiver System, providing internet in Border Areas.

"*BTS construction in several sub-districts in Sangihe Islands Regency*"(WL1IV-4)

"Program to provide internet access to border areas" (WL2IV-4)

"Village data in border areas"(WL3IV-4)

The research findings indicate that high schools in the Sangihe Islands have the geographical characteristics of an archipelago and a border region that significantly impact the implementation of the education digitalization policy. Schools are geographically isolated, with transportation access dependent on sea routes and weather conditions, impacting the distribution of educational resources and the stability of internet services. The research indicates that more than half of high schools still face limitations in basic infrastructure, such as unstable internet connections, limited electricity, and varying levels of human resource readiness in utilizing digital technology. These conditions place high schools in the Sangihe Islands as schools that require special attention in the implementation of the national digital policy. Furthermore, the research findings indicate that the Ministry of Education's policy on school digitalization has provided support opportunities in the form of ICT equipment, access to digital learning platforms, and flexibility in utilizing BOS funds for digital needs. However, the utilization of these inputs has not been fully optimized due to inhibiting factors. Some schools have received or accessed digital devices and internet services, but the effectiveness of their utilization is highly dependent on the accuracy of Dapodik data, the managerial capacity of the principal, and technical assistance from the Education Office. Differences in support between schools have led to varying levels of digital readiness in high schools in the Sangihe Islands.

During the implementation process, this study found that the use of digital technology in several schools in the Sangihe Islands is still predominantly for administrative purposes, such as the Computer-Based National Assessment (ANBK) and school data reporting. The integration of technology into the learning process has not been systematic and sustainable. Key obstacles to the implementation process include limited internet bandwidth and speed, minimal digital pedagogy training for teachers, and the lack of a digital spatial learning model tailored to the island context.

The research findings indicate that the education digitalization policy has had an initial impact in the form of increased student exposure to digital technology. Schools are better prepared to face the demands of technology-based evaluation and digital education development. However, the policy's

impact on improving the quality of learning and student learning outcomes related to digital spatial learning has not been felt evenly. The impacts are still short-term and are heavily influenced by the availability of infrastructure and human resource capacity in each school. These research findings reinforce the view that school digital policies are strategic but require contextual adaptation in their implementation. In all high schools in the Sangihe Islands, national policies have not fully addressed geographic challenges and local limitations without the support of regional and cross-sectoral policies. Therefore, the success of digitalization policies in the archipelago region is determined not only by the provision of devices, but also by strengthening teacher capacity, adaptive digital learning models, and sustainable mentoring. The results of this study also indicate that the digital transformation of education in high schools in the Sangihe Islands requires a more flexible, collaborative, and locally-based policy approach to truly impact the quality of learning.

The North Sulawesi Provincial Government holds a strategic position in supporting the development of digital spatial education, given the characteristics of North Sulawesi, which is dominated by coastal and island areas, including the Sangihe Islands Regency. This geographic condition demands educational policies that are adaptive to spatial challenges and responsive to the development of digital technology as a learning support tool. North Sulawesi Provincial policy support for digital spatial education is reflected in the regional development direction in the 2025-2029 Regional Medium-Term Development Plan (RPJMD) document, which emphasizes digital transformation, strengthening human resource quality, and regional-based development. Education is positioned as a key sector in preparing a young generation with digital and spatial literacy, particularly to support the development of island and border regions. In the education sector, provincial policies serve as a link between national policies and implementation at the district/city level. As a provincial authority, high schools are encouraged to integrate digital technology into their learning in accordance with the Independent Curriculum. This curriculum flexibility provides opportunities for high schools in the Sangihe Islands Regency to develop digital spatial technology-based learning that is contextualized to the coastal, marine, and small island environments. From an infrastructure perspective, the synergy of support from National and Provincial Policies is directed at strengthening information technology facilities and infrastructure in educational institutions, including the procurement of ICT devices, improving internet connectivity, and utilizing digital learning platforms. This policy serves as a crucial foundation for the implementation of digital spatial education, given that spatial technology relies heavily on the availability of adequate devices and networks, particularly in island regions. Furthermore, the North Sulawesi Provincial Government plays a role in enhancing the capacity of human resources in education, particularly high school teachers. Through training programs, workshops, and teacher competency development, North Sulawesi Province encourages increased digital literacy and technology-based pedagogical skills. Strengthening teacher competency is a key factor in the successful integration of digital spatial technology into the learning process. North Sulawesi Provincial policy support is also evident in efforts to encourage cross-sector collaboration, such as cooperation between the Education Office, the Communication and Informatics Office, the Regional Development Planning Agency, and universities. This collaboration opens up opportunities for utilizing regional spatial data as a learning resource, developing locally context-based teaching modules, and providing technical assistance to schools in island regions. Thus, North Sulawesi Provincial policy support for digital spatial education can be understood as part of a human resource

development strategy oriented towards regional characteristics. Although its implementation still faces challenges, particularly related to the equitable distribution of infrastructure and human resource capacity in the archipelago, the North Sulawesi Provincial policy has provided a framework and direction that allows for the gradual and sustainable development of spatial digital education. Spatial digital innovation in the archipelago needs to be systematically supported by increasing the capacity of local human resources (HR) for effective and sustainable implementation. This aligns with the direction of national policies related to HR development and digital transformation as outlined in the 2025–2029 National Medium-Term Development Plan (RPJMN), the National Strategy for Digital Transformation, and the 2025–2029 North Sulawesi Provincial Medium-Term Development Plan (RPJMD) and the 2025–2029 Sangihe Regency Medium-Term Development Plan (RPJMD) regarding Digital Transformation, as well as one of the main policies on welfare and HR in the Archipelago Region. The policy emphasizes that the success of digital transformation is determined not only by the availability of technological infrastructure, but also by the readiness and competence of human resources as users and managers of technology.

In the context of island regions, limited geographic access, disparities in educational quality, and a lack of skilled personnel in spatial technology are key challenges. Therefore, increasing the capacity of local human resources must be directed at mastering digital spatial technical competencies, spatial data analysis skills, and a contextual understanding of the social, economic, and environmental characteristics of island regions. This approach aligns with the principle of region-based development, which places local characteristics as the basis for policy planning. In the education sector, particularly at the high school level, strengthening the capacity of local human resources can be achieved through teacher education and training and developing student competencies in the use of digital spatial technology. The Independent Curriculum provides ample space for the integration of digital technology in learning, including the use of digital maps, satellite imagery, and simple GIS applications in Geography subjects, as well as cross-disciplinary project-based learning. High school teachers in island regions need ongoing training to be able to implement digital spatial learning contextualized to local island conditions. For high school students, mastery of spatial and digital literacy serves not only to improve academic achievement but also as a provision for 21st-century skills relevant to the development needs of island regions. Students who understand spatial technology from an early age have the potential to become superior local human resources capable of contributing to regional planning, disaster mitigation, coastal resource management, and local economic development based on the potential of the islands. Therefore, enhancing the capacity of local human resources through spatial digital education and training is a key strategy in ensuring the sustainability of spatial digital innovation in archipelagic regions. Synergy between national policies, local governments, and secondary education institutions is a determining factor in the success of an inclusive and equitable digital transformation.

In the context of island regions, the development of spatial digital education cannot be implemented sectorally but requires planned, systematic, and sustainable cross-sectoral and cross-regional collaboration. This research finding indicates that geographical limitations, digital infrastructure, and human resource capacity in island high schools require synergy between various stakeholders for effective implementation of education digitalization policies. Cross-sectoral and cross-regional collaboration in spatial digital education is understood as an integrative effort between the central government, local governments, educational institutions, universities, the business and industry

sector, and the community to support the use of spatial-based digital technology for learning. This approach aligns with the educational development paradigm that emphasizes strategic partnerships and collaborative governance. The Ministry of Education's current role in this collaboration focuses on providing national policies, curricula, digital learning platforms, and strengthening teacher competencies through ongoing training. These policies serve as the primary framework for the development of spatial digital education in island high schools. Meanwhile, the Ministry of Communication and Informatics plays a strategic role in providing and sustaining connectivity infrastructure, including school internet services and technology support in hard-to-reach areas.

Provincial and Regency/City Governments play a crucial role in bridging central policies with local needs. Regional governments are responsible for integrating digital spatial education programs into regional development planning, providing accompanying budgets, and facilitating coordination across regional government agencies. Support from regional regulations is a determining factor in the sustainability of policy implementation at the school level. At the educational unit level, high schools (SMA) in all archipelagic regions serve as the primary implementers of digital spatial learning. Schools are expected to integrate spatial technologies, such as digital maps and local geographic data, into contextual learning processes. Utilizing the archipelagic environment as a digital learning resource is a hallmark of this policy's implementation. Universities contribute through academic mentoring, developing digital spatial learning models, and conducting applied research relevant to the needs of island schools. The results of university research and community service can serve as the basis for strengthening learning innovation and evaluating digital education policies. Business and industry, particularly in the technology and geospatial sectors, act as supporting partners through the provision of software, strengthening technological capacity, and implementing corporate social responsibility (CSR) programs in education. This collaboration can open up opportunities for project-based learning.

The North Sulawesi Provincial Government plays a strategic role in encouraging the implementation of digital spatial-based educational innovations through various supporting policies and programs. Digital spatial educational innovations emphasize the use of geospatial technologies, such as Geographic Information Systems (GIS), digital mapping, and spatial visualization applications, to improve students' conceptual understanding and spatial thinking skills (Lasulika & Lukum, 2025). The North Sulawesi Provincial Government's policy support can be realized through several mechanisms, including the provision of technological infrastructure, teacher capacity development, software and hardware provision, and the integration of digital spatial learning into the high school curriculum. In the Sangihe Islands, a region characterized by its archipelagic nature and geographical limitations, the role of the North Sulawesi Provincial Government is crucial in reducing the gap in technology access and facilitating effective educational innovation.

The literature indicates that government policy support for technology-based education can be divided into three main categories:

1) Improving Technological Infrastructure: The provincial government can increase internet access in schools, provide computer equipment, and build intranets or local servers to support digital spatial applications (Widiyatmoko et al., 2024). In the Sangihe Islands, this infrastructure is crucial due to limited access between islands and varying infrastructure.
2) Teacher Competency Development: Training programs and workshops for teachers are crucial for the effective implementation of digital spatial innovations. Research shows that

teacher competency in using GIS and digital applications directly influences the success of technology-based learning (Tusam et al., 2025). The provincial government, through the Education Office, can conduct regular training focused on integrating digital spatial technology into the curriculum.

3) Integration of Curriculum Policy and Learning Innovation: Policy support also includes curriculum arrangements that enable the integration of digital spatial technology into geography and science subjects, as well as project-based or inquiry-based learning models that utilize spatial data and applications. Dewi et al. (2025) stated that an adaptive curriculum that utilizes local spatial data increases the relevance of learning and enhances students' critical thinking skills.

Clear and structured policy support can minimize barriers to the implementation of digital spatial-based educational innovations. For example, providing a stable internet connection and GIS devices in high schools in the Sangihe Islands Regency allows teachers to implement project-based learning relevant to the local context, such as disaster risk mapping, public facility distribution, and natural resource management. However, the literature also shows that implementation in the Sangihe Islands Regency area faces unique challenges, including budget constraints, difficult distances between islands, and the technical readiness of teachers and students (Widiyatmoko et al., 2024; JTPP, 2025). Therefore, policy support needs to be holistic, encompassing the provision of infrastructure, human resource capacity building, and curriculum policies that are adaptive to local conditions.

Several strategies that the North Sulawesi Provincial Government can implement to increase the effectiveness of digital spatial innovation implementation include:

1) Providing an integrated digital infrastructure package for schools in the island region.
2) Ongoing training for teachers and education personnel on the use of GIS and digital spatial applications.
3) Providing digital spatial-based learning modules relevant to local conditions.
4) Collaborating with universities or research institutions for technical assistance and learning content development (Dewi et al., 2025).

This strategy is expected to strengthen the impact of educational innovation on student achievement and improve the quality of technology-based learning in the Sangihe Islands Regency.

Factors Influencing the Implementation of Spatial Digital-Based Educational Model Innovation in Sangihe Islands Regency, North Sulawesi Province

Based on the results of field interviews, data from Principal and Teacher informants revealed that several supporting factors influence the implementation of the digital spatial-based education model in the Sangihe Islands Regency, namely the availability of Wi-Fi and digital devices, resources in the form of teaching staff, parents, the community, industry and the world of work, related stakeholders and the government, and the availability of spatial data. Meanwhile, the supporting factors that are already available at the school are said by the Principal informant to be an internet network, a computer lab, LCDs, and laptops.

"Availability of good wifi and digital tools and devices" (WK1V-1)
"Digital-based infrastructure and resources or teaching staff, parents and the community, industry and the world of work, related stakeholders and the government" (WK3V-1)
"Adequate human resources facilities and infrastructure and availability of spatial data" (WK5V-1)
"What's in the school: internet network, Progress Lab, LCD, Laptop" (WK6V-1)

In addition to supporting factors, data was also obtained from interviews with principals and teachers regarding obstacles to the implementation of spatial progress in the Sangihe Islands Regency, namely poor electricity and Wi-Fi services, where electricity often goes out and is not evenly distributed across all areas. Other obstacles include the availability of competent teachers, the existence of blank spots, inadequate infrastructure, parents' lack of understanding of digital learning, regulations prohibiting cell phones among teenagers, and regional geographic factors.

"Poor electricity service, poor wifi service, inadequate digital tools/devices" (WK1V-2)

"The electricity network is often cut off, human resource availability, internet access with limited bandwidth" (WK2V-2)

"There are still blank spot areas, Lack of contribution from the District Government in supporting the Digitalization of Education for residents, Lack of understanding of parents regarding students' interest in digital-based learning, Cons of using cellphones and the internet among teenage students" (WK3V-2)

"Infrastructure is inadequate, especially on Kahakitang Island, where electricity is only available at night, and even then, for only four hours. Internet access is also slow and often disconnected in the early morning and late afternoon" (WK5V-3)

"Digital divide and teacher capabilities" (WG1V-3)

From interviews with Principal informants, they proposed or recommended further development of spatial digital learning such as equal distribution of internet services in all areas of the Sangihe Islands Regency as well as the provision of digital infrastructure, teacher training, skills certification, electricity and network repairs, and infrastructure improvements related to electricity and the internet.

"Equal distribution of good wifi services in all areas of Sangihe as well as equal distribution of IT or digital equipment assistance" (WK1V-3)

"*For vocational schools, especially those with TKJ expertise programs, it is mandatory to take the LSP P3-based Competency Certification Test which is implemented by vocational schools in collaboration with professional associations"* (WK3V-3)

"The government is providing and repairing electricity and networks, so schools can use technology properly".

"Teacher competency needs to be upgraded; repairs to the underwater internet network which has not been repaired to date, addition of power generators or alternatives to adequately serve the community" (WK6V-3)

Interviews with principals revealed data on the role of the community and parents in supporting digital spatial learning, with some strongly supporting it, while others were less involved or disapproving. Meanwhile, the community, particularly in areas related to internet needs and digitalization, was very supportive.

"The community and parents are very welcoming" (WK1V-4)

"There are those who agree and there are those who disagree" (WK4V-4)

"Parents: less involved. Society: entrepreneurs in fields related to internet and digitalization" (WK6V-4)

Support for training related to spatial digital learning in schools according to the Principal informants comes from progress with the University, progress parties related to training and school leaders.

"For now there are none" (WK1V-5)

"With the North Nusa Polytechnic" (WK2V-5)

"Yes. We, SMK, have a Cooperation Agreement (PKS) with DUDI for the progress of Curriculum Alignment, Student Internships/PKL, and Guest Teacher Programs" (WK3V-5)

"There is support from the Central Leadership of Muhammadiyah" (WK4V-5)

Field research findings indicate that government policies, both at the national and regional levels, are key supporting factors in the development of digital spatial education. School digitalization programs, strengthening information and communication technology (ICT) literacy, and affirmative action policies for the 3T (frontier and outermost) regions provide the legal and structural basis for schools in island regions to integrate digital and spatial technology into learning. These policies serve as an umbrella, enabling schools to implement technology-based learning innovations, even with limited resources. The findings indicate that the geographic characteristics of island regions are actually a supporting factor in the implementation of digital spatial education. The region's complex landscape of islands, coastal areas, and seas makes learning based on digital maps, Geographic Information Systems (GIS), and spatial data highly relevant. Digital spatial learning enables students to understand their living space more contextually, thereby enhancing the meaningfulness of the learning process. Although not yet evenly distributed, field research findings indicate an increasing availability of technological infrastructure in island schools and communities, such as internet access, digital devices, and electricity. Support from government and private sector programs related to the provision of ICT networks and devices is a crucial supporting factor enabling the gradual and sustainable implementation of digital spatial learning.

Teachers are key actors in the development of digital spatial education. Research findings indicate that teachers' motivation to innovate, openness to technology, and digital literacy skills are significant supporting factors. Teachers who are willing to learn and participate in digital technology training are able to adapt spatial learning materials to local conditions and student characteristics. Support from principals and school management plays a crucial role in encouraging the implementation of digital spatial education. Research findings indicate that internal school policies, such as allocation of learning time, utilization of ICT resources, and support for teacher professional development, strengthen the sustainability of digital spatial learning programs in island schools.

This study found that parental and community involvement is a significant external supporting factor. Parents play a role in providing a digital learning environment at home, while local communities provide authentic spatial learning contexts and resources. School collaboration with community members, such as village officials and local communities, enriches digital spatial learning with real-world data and experiences. The research findings indicate significant opportunities for cross-sector collaboration in supporting digital spatial education. Collaboration with universities, government agencies, and related institutions opens access to spatial data, provides technical assistance, and increases the capacity of teachers and students. This collaboration is a strategic supporting factor in accelerating the adoption and improving the quality of digital spatial learning in island regions. High school students in island regions are close to the natural environment and space-based activities in their

daily lives. The research findings indicate that these conditions support the development of students' spatial and visual thinking skills. Digital spatial education is an effective means of connecting students' empirical experiences with academic concepts. Utilization of educational funding sources, such as BOS funds and ICT infrastructure assistance, is a supporting factor in the provision of tools and the development of digital spatial learning. The research findings indicate that despite limited funds, proper management can support the initial implementation of digital spatial education in island schools. The research findings also indicate that curriculum flexibility, particularly through project-based learning, supports the integration of spatial digital education. Local area mapping projects, coastal environmental analysis, and disaster mitigation studies provide relevant and meaningful implementation opportunities for students in the archipelago. Overall, the findings and analysis in this study indicate that the development of spatial digital education in the archipelago of the Sangihe Islands Regency requires support from a combination of policy factors, geographic context, human resources, infrastructure, and cross-stakeholder collaboration. These factors interact with each other and form a spatial digital learning ecosystem that is adaptive to the conditions of the archipelago.

School proposals for further development of digital spatial education are aimed at improving electricity network infrastructure, IT or digital resources, and enhancing teacher competency. The limited and unstable electricity supply in the Sangihe Islands Regency presents a significant obstacle to the implementation of learning in schools, particularly digital and spatial-based learning. Periodic power outages directly disrupt the teaching and learning process, such as the interruption of the use of computers, projectors, and internet access. This situation prevents consistent and sustainable implementation of digital spatial learning. Schools often have to adjust learning schedules or revert to conventional learning methods when electricity is unavailable. These findings indicate that electricity infrastructure is a fundamental prerequisite for the successful implementation of digital spatial education in island regions. Furthermore, limited backup power sources, such as generators or alternative energy systems, increase schools' vulnerability to operational disruptions. In the context of the Sangihe Islands Regency, electricity issues not only impact the technical aspects of learning but also affect teacher and student motivation to develop technology-based learning innovations.

The community and parents have a strategic role in creating a supportive ecosystem for digital learning outside of school, particularly in ensuring the sustainability, relevance, and inclusivity of student learning. Parents play a role in providing basic access to digital learning at home, such as devices, internet connectivity, and a conducive learning environment. Furthermore, parental guidance in technology use helps students utilize digital media productively, safely, and in accordance with learning objectives. Through supervision and habituation, parents and the community contribute to instilling digital ethics, responsibility, and critical thinking skills regarding digital information. This is crucial for preventing technology misuse and improving the quality of students' independent learning outside of school.

The community environment can function as a context-based digital learning laboratory, for example, by utilizing technology to document regional potential, local wisdom, or social issues. In the context of island regions, communities can support digital learning that is relevant to local geography and culture. Synergy between schools, parents, and the community strengthens the sustainability of digital learning. This collaboration includes sharing best practices, digital literacy training, and support for technology-based school programs implemented outside of formal school hours. Community

involvement, including traditional leaders, religious leaders, and community organizations, provides social legitimacy to digital learning. This support contributes to program sustainability and encourages students' active participation in lifelong learning. Overall, the role of parents and the community is not only complementary to schools but also a key element in building a digital learning ecosystem that is integrative, adaptive, and sustainable outside the formal school environment.

Field findings indicate that parents and community members lack an adequate understanding of the concept, objectives, and benefits of digital learning. These limited digital literacy issues raise concerns and resistance, as parents feel unable to support or supervise their children's technology-based learning activities. Some members of the public view the use of digital devices as having more negative impacts than positive ones, such as device addiction, decreased social interaction, and exposure to age-inappropriate content. This perception leads to digital learning being perceived as risky for children's moral and social development. Parents worry about the difficulty of controlling their children's internet activities, especially outside of school hours. Concerns about access to social media, online games, and content are the main reasons for their rejection of digital learning. Inequality in access to electricity, digital devices, and internet networks in the home environment leads to digital learning being perceived as an additional burden for families. In the context of an archipelago, this situation reinforces the view that digital learning is unrealistic and has the potential to cause injustice to students. Some parents also oppose digital learning due to economic constraints, unable to afford internet subscriptions, as internet is still considered expensive. Procuring devices, data plan costs, and maintaining technology are seen as financial burdens that not all families can sustain..

Research findings indicate that the lack of effective outreach from schools regarding the goals, mechanisms, and benefits of digital learning has led to misunderstandings among parents and the community. When digital learning is not comprehensively explained, parents tend to become defensive and resist change. In some communities, conventional face-to-face learning is still considered the only legitimate and effective form of learning. Digital learning is perceived as contradicting long-rooted values of togetherness, discipline, and teacher authority in local cultures. Suboptimal experiences during online learning (for example, during the pandemic) have shaped negative perceptions of digital learning in general. Parents tend to generalize these experiences, deeming digital learning ineffective and burdensome for students. Some parents doubt the ability of digital learning to improve students' academic understanding and character. Digital learning is viewed as merely a supplement, not a primary approach with pedagogical value equal to face-to-face learning. Overall, public and parental disapproval of digital learning is not solely driven by a rejection of technology, but rather by a combination of literacy, economics, infrastructure, prior experience, and socio-cultural factors. These findings indicate that the successful implementation of digital learning—including spatial digital learning—is highly dependent on communication strategies, parental empowerment, and a contextual approach sensitive to local conditions.

To improve the quality of education, cross-sectoral and cross-regional collaborative networks with academic institutions and the private sector are strategic factors in strengthening human resource capacity to support the development of spatial digital education, particularly in island regions. Research findings indicate that limited internal school resources, both in terms of teacher competency and availability of facilities, require sustainable and structured external support. Academic institutions play a crucial role in providing scientific and pedagogical expertise related to spatial technology. Universities

have competent lecturers and researchers in the fields of Geographic Information Systems (GIS), remote sensing, and spatial analysis. Through these collaborations, schools gain access to research-based training, academic mentoring, and the development of spatial digital learning modules tailored to the curriculum and local context of island regions. Furthermore, private sector involvement contributes significantly to technical aspects and technological innovation. Technology companies, software providers, and geospatial-based industries have practical experience and access to the latest tools and applications. Collaboration with the private sector enables practical training, oriented to field needs, and introduces best practices in the use of spatial technology. Collaboration between academics and the private sector serves as a bridge between theory and practice. Research findings indicate that purely theoretical digital spatial training is less effective in improving teacher and student competency. By simultaneously involving academics and industry practitioners, training becomes more contextual, applicable, and sustainable. Cross-sector collaboration strengthens the sustainability and scalability of training programs. Academic support ensures scientific quality, while private involvement opens up opportunities for resource support, technology updates, and professional networking. This synergy forms a crucial foundation for developing a digital spatial education ecosystem that is adaptive to technological developments. In the context of an island region like the Sangihe Islands Regency, this collaboration plays a role in reducing the region's digital divide. Through structured training programs and ongoing mentoring, teachers and students in the island region gain more equal opportunities to access and utilize digital spatial technology.

Based on findings and analysis, collaboration with academics and the private sector is not merely a supporting option but a strategic necessity in the development of digital spatial education. Cross-sector collaboration enables competency enhancement, learning innovation, and program sustainability, enabling digital spatial education to develop effectively and contextually in the archipelago. The implementation of digital spatial education innovations in high schools in the Sangihe Islands Regency aims to improve students' spatial thinking skills, analyze geographic data, and solve problems based on environmental contexts. Digitizing learning through geospatial technology includes the use of Geographic Information Systems (GIS), Google Earth, 3D mapping, and spatial data visualization applications (Lasulika & Lukum, 2025). In the Sangihe Islands Regency, a region consisting of islands with limited access, digital spatial education innovations are highly relevant. Implementing these innovations allows students to connect theoretical learning with real-world phenomena in the local environment, such as disaster mitigation, public facility distribution, and natural resource management. Based on a literature review, several key factors influence the successful implementation of digital spatial education innovations:

1) Technological Infrastructure Readiness. Adequate infrastructure, including internet access, computer equipment, and digital spatial software, is a key prerequisite. Widiyatmoko et al. (2024) demonstrated that technology availability impacts teachers' ability to implement GIS-based learning. In the Sangihe Islands, limited infrastructure in some schools is a major challenge, making government and school support crucial.
2) Teacher Competence. Successful implementation depends heavily on teachers' ability to utilize digital spatial technology. Tusam et al. (2025) emphasize that ongoing teacher training in GIS use and technology integration into the curriculum enhances learning effectiveness.

Teacher competencies include technical and pedagogical understanding, as well as the ability to facilitate spatial data-based projects.

3) Student Readiness and Digital Literacy. Students' digital literacy is a determining factor. Students with higher technological skills tend to more easily understand spatial concepts and actively engage in project-based learning. Dewi et al. (2025) demonstrate that strong digital literacy facilitates student adaptation to GIS-based learning and other spatial applications.
4) Policy and Curriculum Support: Support from the North Sulawesi Provincial Government and high schools, including the provision of policies, budgets, and adaptive curriculum integration, influences implementation. Lasulika & Lukum (2025) emphasize that clear policies, including the provision of digital modules and technology-based curriculum development, encourage the consistent implementation of educational innovations.
5) Geographic and Local Context: The geographical conditions of the Sangihe Islands Regency, such as distance between islands, transportation limitations, and the distribution of the school population, influence implementation strategies. The use of digital spatial technology can address these limitations through virtual learning or project-based mapping that emphasizes the local context.

Factors Inhibiting Implementation

The literature highlights several obstacles to the implementation of digital spatial education innovations in the Sangihe Islands Regency:

- Limited Infrastructure and Technology Access – unstable internet connections, limited computer availability, and incomplete software (JTPP, 2025).
- Variation in Teacher Competence – teachers who are poorly trained in the use of digital spatial technology tend to struggle to implement innovations effectively (Widiyatmoko et al., 2024).
- Diverse Student Readiness – differences in digital literacy among students can impact the speed and effectiveness of learning.
- Administrative and Budgetary Constraints – limited funds to purchase devices and facilitate training are a widespread barrier.

To maximize the implementation of digital spatial education innovations in the Sangihe Islands Regency, the following strategies can be implemented:

1) Provision of integrated digital technology infrastructure for schools in the island region.
2) Continuous training for teachers on GIS use and the use of digital spatial technology in learning.
3) Integration of digital spatial-based learning modules appropriate to the local context.
4) Policy and budget support from the provincial government to ensure the sustainability of innovation.
5) Implementation of a Project-Based Learning approach relevant to local geographic conditions to optimize student engagement.

With this strategy, barriers related to infrastructure, teacher competency, and student readiness can be minimized, allowing spatial digital-based educational innovations to improve the quality of learning and student achievement. Discussions about advanced educational models become irrelevant if the basic prerequisites—electricity and connectivity—remain problematic. This finding is consistent with innovation theory, which states that successful technology adoption is highly dependent on

environmental readiness (Rogers, 2003). The innovation model in Sangihe is hampered by geographical challenges and the development of basic infrastructure, which should be the primary focus of digital equity policies in 3T areas. The school policy banning smartphones is a clear example of policy incoherence. On the one hand, schools are encouraged to digitally transform; on the other, the most personal and powerful digital tools are prohibited. This reflects the school system's unpreparedness to manage the risks and capitalize on the opportunities of bring-your-own-device (BYOD) technology. Smarter school policies are needed that, rather than prohibiting, regulate and guide positive use. The success of vocational high schools (SMK) in implementing digital-spatial learning demonstrates that when the curriculum is specifically designed, the outputs are measurable and relevant to competency needs. Senior high schools, with their more general curricula, face more complex integration challenges. This suggests the need to develop specific digital-spatial literacy modules or programs that can be adopted by senior high schools, inspired by the success of vocational high schools but adapted to the general education context. The student responses in this study were not simply feedback, but rather in-depth analyses covering the benefits, barriers, and practical solutions. They are digital natives who understand the potential and pitfalls of technology. Their proposals for teacher training, infrastructure improvements, and revisions to the cellphone ban policy demonstrate their capacity as agents of change and partners in the educational transformation process. Ignoring their voices means ignoring the perspectives of key users.

Based on the findings, a spatial digital education model for island regions cannot be one-size-fits-all or solely focused on pedagogical and content aspects. The model must be holistic and contextual, encompassing four pillars:

1) Infrastructure Pillar: Ensuring stable and affordable electricity and internet access.
2) Policy Pillar: Developing guidelines for technology use in schools that support learning, including educational smartphone regulations.
3) Capacity Pillar: Providing ongoing, practical, and appropriate teacher training, addressing the region's limited resources.
4) Partnership Pillar: Building collaborations with universities, the private sector, and communities to provide content, tools, and mentoring.

The implementation of spatial digital education innovations in the Sangihe Islands Regency fundamentally addresses the challenge of equitable access to education, as outlined by Syafii (2018). As a 3T (Underdeveloped) region, Sangihe Islands Regency faces challenges in physical access. This innovation provides a Virtual Access solution, effectively "eliminating" distance (Valente, 2019) and providing opportunities for border students to access global information. The use of spatial applications specifically provides added value, namely Geopolitical Contextualization. Students not only learn Geography from textbooks, but analyze their own border environment using spatial data. This is an implementation of strengthening character education (Model Implementation Strengthening Character Education, 2017) that is relevant to students' identities as citizens in frontier regions. Findings regarding increased student motivation and easier understanding of concepts (evident from teacher and student responses) support the theoretical framework of School Effectiveness (Scheerens, 2013).

In Scheerens' model, the quality of the learning process and a positive school climate are the main predictors of learning outcomes. The Digital Spatial Model has successfully:

1) Improved Process Quality: By changing the method from passive lectures to interactive/visual ones.
2) Created an Innovative Climate: By encouraging teachers to self-train and form Learning Communities (Thullberg & Millstam, 2010).

However, this effectiveness is threatened by the instability of environmental inputs (electricity and signal). Therefore, school effectiveness in the Sangihe Islands Regency currently depends heavily on infrastructure resilience. The absence of specific regulations and the instability of cross-sectoral infrastructure indicate resistance (Weerbarstigheid) to innovative change at the institutional level, a concept promoted by Werkman, Boonstra, & Elving (2005). Weerbarstigheid (rigidity or resistance) in this context does not refer to teacher or student resistance, but rather to systemic resistance represented by:

1) Budget Shortage: Lack of local budget to prioritize quota subsidies or signal strengthening due to the absence of binding regulations.
2) Failure of Mandatory Synergy: Despite the Smart City Vision (Bappeda), the failure of service providers (PLN/KOMINFO) to ensure stability indicates that this synergy is not yet mandatory.

To ensure the sustainability of this innovation, it must be elevated from the initiation level to the institutionalization level. This discussion concludes that the implementation of the Digital Spatial Education Model innovation in the Sangihe Islands requires an Education-Based Development paradigm. Issues with electricity, signaling, and transportation can no longer be considered external to the education sector, but rather as core prerequisites for educational success.

A Joint Regulation of Regional Heads is needed that integrates:

- Education (Dikda): Curriculum adaptation and human resource development.
- Planning (Bappeda) and the Regional Border Management Agency: Budget allocation for strengthening school networks in Smart City planning.
- Infrastructure (PUPR/KOMINFO): Ensuring network quality and stability in schools in the 3T (outermost) regions.

This institutionalized synergy is the only way to transform Sangihe from an isolated 3T region into a "Digital Gateway" for education in border areas.

CONCLUSION

The readiness of spatial digital technology infrastructure in the Sangihe Islands, North Sulawesi Province, is less than optimal, characterized by limited access to electricity, uneven internet connectivity, and limited availability of supporting facilities and equipment in some areas of the archipelago. Nevertheless, there is potential and initial initiatives in utilizing spatial digital technology that can be further developed. Therefore, strengthening basic infrastructure, policy support, and cross-sector collaboration are needed so that spatial digital infrastructure readiness can effectively support the implementation of educational innovations and improve the quality of learning in the archipelago. The implementation of the spatial digital technology curriculum in high schools in the Sangihe Islands, North Sulawesi Province, has begun but has not been optimal. This condition is influenced by limited

infrastructure, variations in teacher competency, and the uneven integration of spatial digital learning into school curriculum practices. Nevertheless, the potential for implementing this curriculum is quite large because it is relevant to the characteristics of the archipelago region. Therefore, strengthening policy support, increasing human resource capacity, and providing supporting facilities for effective and sustainable spatial digital learning. Digital spatial-based educational innovations at Sangihe Islands Senior High Schools, North Sulawesi Province, have not been optimally implemented, resulting in a lack of positive impact on student achievement, particularly in improving spatial thinking skills, problem-solving, and understanding of local environmental contexts. These digital spatial-based educational innovations have not yet positively impacted student achievement because they are still influenced by limited infrastructure, teacher competency, and the availability of learning resources. If adequate facilities, teacher training, and more systematic learning integration are available, these digital spatial innovations will have the potential to significantly improve student achievement and motivation. The North Sulawesi Provincial Government's policy support for the implementation of digital spatial-based educational innovations in Sangihe Islands Regency has not yet shown any supporting regulations and programs, so they still need to be strengthened by issuing more specific policies, allocating sustainable budgets, and coordinating across sectors and regions. Strengthening these policies is crucial to ensure the availability of facilities, teacher training, and effective monitoring and evaluation, so that digital spatial educational innovations can run optimally and sustainably. The implementation of digital spatial education innovations in the Sangihe Islands is influenced by various factors, including the readiness of technological and electrical infrastructure, teacher competence, school readiness to integrate innovations into the curriculum, policy and funding support, and parental and community acceptance. These factors are interrelated and determine the effectiveness and sustainability of innovations. Therefore, integrated strengthening is needed to ensure optimal implementation of digital spatial education and a positive impact on student learning.

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