Vol 42, No 2 (2025): October 2025

Jurnal Penelitian Pendidikan

https://journal.unnes.ac.id/journals/JPP

Gadis Antariksa Icon: Fostering Environmental Awareness through Mangrove Ecosystem Education

Indri Rosemaya Whisnuwardani, Nita Noriko, Nunung Nurhasanah

Universitas Al-Azhar, Indonesia

Abstract

Innovation in mangrove ecosystem education is crucial for engaging younger generations in global climate change mitigation efforts. This study employs a qualitative approach to develop a Knowledge Capture (KC) model using Soft System Methodology (SSM), providing a framework aligned with knowledge objectives: normative, operational, strategic, and interactive planning. The CATWOE analysis (Customers, Actors, Transformation, Worldview, Owners, Environment) is applied to understand complex interactions within social and organizational systems, ensuring all stakeholder perspectives are considered. The learning innovation is structured through eight stages: Focus Group Discussions with educators, environmental observation, knowledge management via applied science seminars, evaluation and development of climate change activities, collaborative development, cross-subject collaboration, development of a Phase E Biology teaching module, and establishment of a science greenhouse for education. The results demonstrate that the Knowledge Capture process using the SSM approach effectively advances mangrove ecosystem education as a climate change mitigation strategy. Quantitative validation employed questionnaires analyzed with a Likert scale to assess participants' knowledge and attitudes, confirming high instrument validity and reliability. These findings affirm the potential of the Gadis Antariksa Icon, fostering environmental awarness through mangrove ecosystem education.

Keywords: Gadis Antariksa Icon, mangrove ecosystem education, climate change mitigation, Knowledge Capture model, Soft System Methodology

INTRODUCTION

Indonesia faces a state of emergency due to global climate change, necessitating urgent attention and effective mitigation actions to reduce its impact on the environment and natural resources. Global climate change encompasses alterations in climate elements such as temperature, pressure, humidity, rainfall, and wind patterns. In 2023, a recorded increase in temperature reached 1.5°C, highlighting the urgency of the climate crisis, which significantly affects human life through extreme weather events, threats to food security, and natural disasters (Irma & Gusmira, 2024). The consequences of global climate change are profound, leading to natural disasters, erosion, flooding, shifts in wetland ecosystems, and changes in water quality (Fitria & Dwiyanto, 2021).

As the country with the largest mangrove forest area in the world, Indonesia's mangrove ecosystems play a crucial role in carbon absorption through photosynthesis, thereby reducing atmospheric carbon dioxide levels. According to the Ministry of Environment and Forestry, the total area of mangroves is estimated to be 3,364,076 hectares (Rahmadi et al., 2023). These ecosystems provide essential ecological functions, offering environmental services and serving as valuable resources for educational initiatives (Thank You et al., 2024). However, the degradation of mangrove forests, primarily driven by human activities such as illegal logging and land-use changes, poses a significant threat to their sustainability. This degradation results in habitat loss for species dependent on mangroves, decreased fisheries productivity, and an increased risk of natural disasters (Mandar et al., 2024; Zega et al., 2024; Simbolon et al., 2024).

Mangrove ecosystems also act as natural filters, protecting river basins (Daerah Aliran Sungai (DAS)) from water pollution and industrial waste, which can adversely affect coastal ecosystems. A critical factor contributing to the damage of mangrove ecosystems is the lack of community knowledge and compliance, coupled with insufficient enforcement of environmental regulations (Harefa et al., 2024). Improper waste disposal harms the roots of mangrove trees, reducing their ability to absorb nutrients and impacting their growth and health (Sairmorsa & Tetelepta, 2024).

Effective management and conservation of mangrove ecosystems are essential for environmental

preservation and serve as a primary strategy in global efforts to reduce greenhouse gas emissions resulting from global warming. Local environmental education initiatives centered on mangroves have been implemented in various regions, promoting awareness and understanding of these vital ecosystems (Andy et al., 2022). Such educational programs can be integrated into school curricula, enhancing students' knowledge and fostering a sense of responsibility toward environmental protection.

Extracurricular activities can further enhance creativity and foster student research and innovation (Tiffani et al., 2024). Engaging students in environmental education initiatives promotes positive change and empowers the younger generation to address the challenges posed by climate change. This approach cultivates a sense of pride and love for their homeland and its natural resources, encouraging students to contribute to sustainable solutions from an early age (Hajunilato & Sumaryanti, 2024).

To analyze the complexities of learning about mangrove ecosystems, this study employs the Soft System Methodology (SSM), providing a comprehensive understanding of the challenges associated with this educational topic. The conceptual model developed in this study is categorized into three dimensions relevant to mangrove ecosystem education activities: normative, operational, and strategic. These dimensions relate to innovations in learning about mangrove ecosystems in the context of mitigating global climate change. The anticipated perspective, referred to as "holon" in SSM, emerges from innovative learning activities designed to meet knowledge needs.

The aim of this study is to implement and evaluate the mangrove ecosystem learning innovation strategy proposed by the Gadis Antariksa movement through the Knowledge Capture (KC) model. This model is structured to assist stakeholders in making informed and sustainable educational decisions, ultimately fostering environmental awareness and engagement among youth.

METHOD

The use of Soft System Methodology (SSM) is aimed at action-oriented processing in problematic situations. In real life, learning through SSM begins with recognizing situations to formulate or implement actions that improve these problematic circumstances. The learning process occurs in an organized manner within real situations, explored using intellectual tools that facilitate action or execution, as referenced in various activity models with similar objectives, built upon multiple perspectives (worldview) (Checkland et al., 2006).

In this study, SSM is utilized to map and develop a comprehensive model for knowledge capture, employing the CATWOE framework: Customers, Actors, Transformation, Worldview, Owner, and Environment, with multiple holons to help identify and define existing problems and formulate appropriate solutions. This process involves data collection through interviews and observations, followed by the compilation of a rich picture to describe the current situation. Knowledge Capture (KC), as a component of Knowledge Management (KM), is used for documenting and capturing knowledge.

The research steps are structured within a problem-solving framework. The KC model design is informed by the SSM approach, examining unstructured problems related to awareness and action aimed at mitigating global climate change through innovations in mangrove ecosystem learning. The research design employs qualitative methods to develop the KC model within the context of the Gadis Antariksa strategy for learning innovation in mangrove ecosystems as a mitigation action against global climate change.

Data collection methods include:

1. **Primary Data:**
    a. **Identifying Knowledge:** Discussions and interactions among subject teachers (MGMP Biology, Pancasila Education, and Geography) at the South Jakarta Education Office regarding Natural Resources.
    b. **Analyzing Knowledge:** Conducting seminar activities through KIR, focusing on knowledge of the mangrove ecosystem.
    c. **Developing Knowledge:** Designing Phase E Teaching Modules (Grade X) and creating a Science Greenhouse for educational purposes.
    d. **Observation and Interviews:** Engaging with the Education Sub-Department, school principals, teachers, parents, and students.
2. **Questionnaire Data Collection:**
    a. **Type of Research:** A quantitative approach utilizing an experimental research design, which involves measuring respondents' knowledge and attitudes before (pre-test) and after (post-test) the intervention.
    b. **Research Instruments:** A closed questionnaire employing a 5-point Likert scale, consisting of questions that measure a primary variable, namely knowledge.

c. **Population and Sample:** The study population includes teachers and high school students, specifically Biology and Geography subject teachers in the Special Capital Region (Daerah Khusus Ibukota (DKI)) and high school students in grades X, XI, and XII from South Jakarta, West Jakarta, and North Jakarta. Samples were selected through purposive random sampling, with 30 respondents from each region participating in the pre-test and post-test processes.

The problem-solving framework is illustrated in Figure 1:

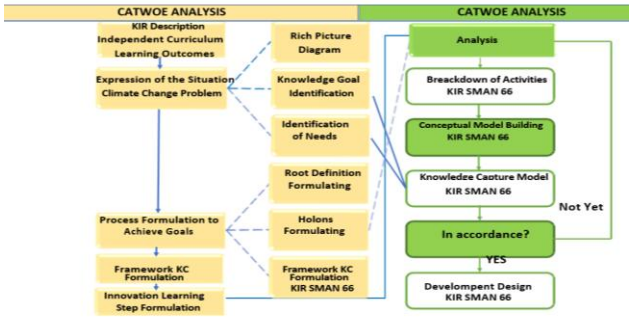

Figure 1. Problem-Solving Framework

To get a better idea of what KIR is, KIR is a community or group consisting of teenagers interested in scientific research. The primary objective of KIR is to cultivate teenagers' interest in science and technology while providing a platform for learning and conducting experiments under the guidance of teachers or trainers. KIR can assist the younger generation in addressing the negative impacts of globalization and foster awareness of the importance of maintaining national sovereignty and interests.

The curriculum is a critical factor in the success of a nation's education system. The education curriculum in Indonesia has undergone numerous changes, including revisions in 1947, 1964, 1968, 1973, 1975, 1984, 1994, 1997, 2004, 2006, 2013, and 2019. These changes have been prompted by the need to enhance knowledge and skills in preparing a generation with character that aligns with the nation's identity and adapts to contemporary developments (Hajunilato & Sumaryanti, 2024).

The Independent Curriculum aims to develop students' character through the Pancasila Student Profile Strengthening Project (Projek Penguatan Profil Pancasila (P5)), which encompasses six dimensions of competence: faith, devotion to God Almighty and noble character, global diversity, mutual cooperation, creativity, critical thinking, and independence. One strategy to enhance students' knowledge of the mangrove ecosystem is by integrating it with science material and encouraging students to explore mangrove areas for a deeper understanding (Tiffani et al., 2024). The implementation of P5 is collaborative and can have a significant educational impact on students (Andy et al., 2022). The mangrove ecosystem can serve as a learning innovation by integrating Biology subjects and local wisdom within the Independent Curriculum. Local wisdom in education can act as a filter for global influences entering community life (Sukmana, 2024). Learning achievements within the Independent Curriculum are based on the developmental phases of students, utilizing an active interaction approach with the environment through various activities designed by teachers (Elvianasti et al., 2022).

RESULT AND DISCUSSION

The first stage of the research was conducted at SMAN 66, South Jakarta, beginning with interviews with the Principal, Biology Teacher, KIR Supervisor, and Head of MGMP South Jakarta 1. Following the interviews, the author attended a Biology class for XII A in the laboratory of SMAN 66, where a discussion was held with 36 students from class XII A. The results of the interviews and discussions revealed individual attitudes, insights regarding the mangrove ecosystem, and learning expectations (Harefa et al., 2024).

The second stage involved conveying the problem situation in the form of a “Rich Picture”, which depicts all the actors involved in the current situation. This process includes an explanation of what is already known by each actor and what still needs to be understood. The relationships between the various elements can be seen in Figure 2:

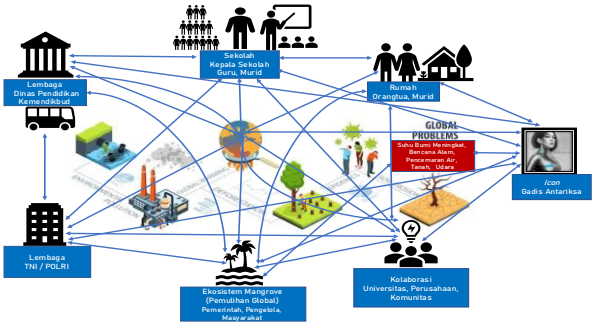

Figure 2.Rich Picture Diagram

The third stage is to design the Root Cause Definition (RD), which involves several stages of CATWOE:

1. **(C)ustomer:** The stakeholders impacted by the transformation include educational institutions, teachers' conferences (Musyawarah Guru Mata Pelajaran (MGMP)), and extracurricular programs focused on environmental education. These groups play a vital role in fostering awareness and understanding of mangrove ecosystems among students.
2. **(A)ctors:** The individuals facilitating the transformation include the Gadis Antariksa Icon, representatives from educational institutions, educators, and community members. Their involvement is crucial in implementing initiatives that promote environmental education and conservation of mangrove ecosystems.
3. **(T)ransformation:** This refers to the process that converts inputs into outputs, specifically the innovative approach to learning about mangrove ecosystems through seminars and workshops, utilizing the Gadis Antariksa Icon Strategy. This includes designing educational collaborations focused on mangrove forests within the framework of global climate change mitigation actions, involving various stakeholders such as local government agencies, environmental organizations, and community groups. Additionally, it encompasses the development of comprehensive learning modules for the mangrove ecosystem through the Gadis Antariksa Icon strategy.
4. **(W)orldview**: This framework perspective provides a contextual understanding of the Root Cause Definition (RD), emphasizing the importance of increasing knowledge and awareness among students and educators regarding the mangrove ecosystem through the Gadis Antariksa Icon strategy. It aims to enhance the effectiveness of collaborative efforts in global climate change mitigation and improve the organization of climate change initiatives through educational programs.
5. **(O)wner**: The primary entity with a vested interest in the transformation is the Gadis Antariksa Icon, which seeks to empower youth and foster environmental stewardship through education.
6. **(E)nvironment**: The external factors that influence but do not control the initiative include limited funding for environmental education related to mangrove ecosystems in various regions. Additionally, government regulations concerning environmental education and global climate change mitigation actions have not received adequate attention. There is a critical need for policies that support environmental education initiatives focused on mangrove ecosystems and their role in climate change mitigation.

The CATWOE analysis describes several holons that play a role in the system being analyzed, focusing on the main elements such as Customers, Actors, Transformation, Worldview, Owner, and Environment. Each holon represents an important part of the transformation process, from the parties who benefit to the environmental factors that influence how the system operates. Through a deep understanding of these components, a comprehensive picture can be obtained regarding the dynamics and interactions between holons in achieving the desired goals. The results of the CATWOE analysis can be seen in Table 1 below:

Table 1. Holon 1, Focus Group Discussion

No	Holon 1 Focus Group Discussion (FGD)
1	**Customers:** On September 10, 2024, a discussion and interaction session was held regarding the management of natural resources, organized by the MGMP Biology

No	Holon 1 Focus Group Discussion (FGD)
	South Jakarta 1 at the Al Azhar University Indonesia (UAI) campus.
2	**Actors:** Participants included the UAI Student Affairs Office, the Education Office, and resource persons from the Natural Resources Management Master's Program (MPSDA) at the Faculty of Science and Technology, UAI. Notable individuals included Mrs. Nita Noriko, Mr. Yunus Efendi, Fiter Romilado, and Indri Rosemaya. A total of 31 teachers from the MGMP Biology, South Jakarta 1, were also involved.
3	**Transformation:** The session featured presentations that included materials showcasing the Gadis Antariksa Icon, which is copyrighted, as well as a conservation video on mangroves produced by UAI MPSDA, focusing on the Taman Wisata Alam (TWA) Angke Kapuk area.
4	**Worldview:** A questionnaire was distributed to the 31 MGMP Biology teachers as a means of evaluation and follow-up regarding the learning innovations related to mangrove ecosystems for students.
5	**Owners:** Al Azhar University of Indonesia (UAI)
6	**Environment:** The effects of global climate change are significantly felt by teachers and have an impact on the mangrove ecosystem. However, these efforts are constrained by budget limitations, policies, and regulations that hinder the provision of real educational experiences for students in relation to mangroves.

Table 2. Holon 2, Environmental Observation

No	Holon 2 Environmental Observation
1	**Customers:** On September 20, 2024, at 09:00, the author arrived at SMAN 66, South Jakarta, to attend the Biology class for XII A as a follow-up to the MGMP Teachers' questionnaire data collected on September 10, 2024. This visit aimed to address the educational constraints related to the real mangrove ecosystem for students.
2	**Actors:** Mr. Deni Boy (Principal), Mrs. Agus Dwi S (Biology Teacher, KIR Supervisor, and Chair of MGMP South Jakarta Region 1), and 36 students from class XII A at SMAN 66, South Jakarta.
3	**Transformation:** From 09:00 to 09:30, the author met with the Principal to explain the purpose of the visit and to request permission to attend the Biology lessons in the laboratory of SMAN 66 to observe student behavior. The Principal expressed strong support for mangrove ecosystem education amidst global climate change and shared experiences from his teaching tenure in the Mentawai Islands, a coastal area. From 09:30 to 11:30, the author entered the laboratory of SMAN 66 to participate in the Biology lessons. Before starting the lesson, Mrs. Agus asked the students to pray, followed by cheers from the students to express their enthusiasm for the lesson. Next, Mrs. Agus introduced students who had achieved success in academics and extracurricular activities, including Tsania (Scout Leader), Danov (OSIS Leader), Ahmad (OSIS Treasurer), Fikri (Class Leader), Faisal (Rohis Leader), Intan (KIR Leader), Agis (Archery Athlete), and other accomplished students. From the moment the author entered class XII A, a strong sense of camaraderie between the teachers and students was evident.
4	**Worldview:** At 09:45, the lesson commenced with a presentation by Group 3, consisting of six students, on their research assignment titled "Use of Herbicides Against Photosynthesis Processes in Gambir Jasmine Plants." The presentation facilitated two-way communication between the teacher and students. Mrs. Agus encouraged students to use their own language while maintaining politeness, allowing them to feel comfortable during their presentations.

No	Holon 2 Environmental Observation
	 *Figure 3 Presentation Activities by Students* Group 3 then invited the audience to the 1st floor to observe the results of the plants after herbicide application.  *Figure 4. Delivery of Crop Results after Watering with Herbicide* Group 3 concluded their presentation with a "pantun", a traditional form of poetry characterized by its structure and rhyming patterns, which elicited applause and laughter from the audience. Following this, Mrs. Agus provided appreciation and feedback to Group 3 regarding their research presentation.
5	**Owners:** SMAN 66, South Jakarta.
6	**Environment:** Thirty minutes before the break ended, Mrs. Agus allocated time for a discussion with students about the mangrove ecosystem. Out of 36 students, only one had previously visited a mangrove. The students expressed enthusiasm for real educational experiences in nature compared to visits to museums. After the discussion, the author toured the school accompanied by Intan, Made, Allysha, and Artika to view the greenhouse used for KIR SMAN 66 extracurricular activities. At 12:05, the author met with Mrs. Agus to determine the schedule for the SMAN 66 KIR extracurricular seminar activity, where the author would serve as a resource person related to the mangrove ecosystem.

Table 3. Holon 3, Management Knowledge

No	Holon 3 Knowledge Management
1	**Customers:** On September 24, 2024, coinciding with National Farmers Day, the KIR SMAN 66 Extracurricular held an Expert Seminar and Applied Science Study.  *Figure 5. KIR SMAN 66, South Jakarta*
2	**Actors:** Mr. Deni Boy (Principal), Mrs. Agus Dwi (Biology Teacher, KIR Supervisor, and Chair of MGMP South Jakarta 1), Mr. Wildan (KIR Trainer), the author as Resource Person, and 58 KIR members (students from grades X, XI, and XII).
3	**Transformation:** Seminar materials included an introduction to the Gadis Antariksa Icon, screening of the MPSDA UAI mangrove conservation video, explanations of the mangrove ecosystem, and interactive games. Students who answered the game questions correctly received a ticket for a real educational visit to the mangrove ecosystem in TWA Angke Kapuk.
4	**Worldview:** The seminar was held from 15:30 to 17:30. It concluded with the awarding of certificates and KIR uniforms of SMAN 66 to the author as a Resource Person, presented by Mr. Deni Boy (Principal), along with the awarding of books by Mrs. Agus Dwi.
5	**Owners:** Extracurricular KIR SMAN 66, South Jakarta
6	**Environment:** The mangrove ecosystem is significantly influenced by global climate change; however, students' understanding is minimal, as only 7 out of 58 students who attended the seminar had previously visited the mangroves.

Table 4. Holon 4, Evaluation and Development

No	Holon 4 Evaluation and Development
1	**Customers:** On October 6, 2024, at 07:00, participants gathered at SMAN 66, South Jakarta.
2	**Actors:** Vice Principal for Student Affairs, Mrs. Agus Dwi (KIR Supervisor), Mr. Wildan (KIR Trainer), 2 parents of students, 12 students, and the author.
3	**Transformation:** The author invited students to tour the mangrove area and explained the function of the mangrove ecosystem in mitigating global climate change.  *Figure 6. Mangrove Forest Live Education*
4	**Worldview:** KIR SMAN 66 created a poster featuring the word "Gadis Antariksa" at the initiative of the students. After the mangrove ecosystem education, a mangrove tour by boat followed.  *Figure 7. Mangrove Tour by Boat*
5	**Owners:** SMAN 66, South Jakarta.
6	**Environmental:** Mangrove ecosystems significantly impact global climate change, but students' understanding of these ecosystems is minimal, particularly regarding their role in mitigating global climate change. The real educational activities concluded at 14:00, with the group returning to SMAN 66 by 15:00.

Table 5. Holon 5, Collaborative Development

No	Holon 5 Collaborative Development
1	**Customers:** On November 3, 2024, at 08:00, participants gathered at SMAN 66, South Jakarta.
2	**Actors:** Vice Principal for Student Affairs, Mrs. Agus Dwi (KIR Supervisor), 78 students, and the author.
3	**Transformation:** 12 students who had been educated about the mangrove forest (game winners) explained mangroves to 78 students, divided into 12 groups.   *Figure 8. Students Educating 12 Groups*
4	**Worldview:** Students participated in education related to the mangrove ecosystem through the Angke Kapuk TWA Mangrove Management.  *Figure 9. Mangrove Forest Education*

No	Holon 5 Collaborative Development
	 *Figure 12. Mangrove Games*
5	**Owners:** SMAN 66, South Jakarta.
6	**Environmental:** Mangrove ecosystems have a significant impact on global climate change, but students' understanding of these ecosystems is minimal, especially regarding their role in mitigating global climate change. The real educational activities concluded at 14:00, with the group returning to SMAN 66 by 15:00.

Table 6. Holon 6, Collaborative of MGMP Pancasila Education, Biology and Geography South Jakarta Education Sub-dept.Area 1

No	Holon 5 Collaborative Development
1	**Customers:** MGMP Pancasila, Biology, and Geography, South Jakarta Education Sub-department Area 1.  *Figure 10. MGMP Poster Collaboration*
2	**Actors:** 51 MGMP teachers from Pancasila Education, Biology, and Geography in South Jakarta Education Sub-department Area 1.  *Figure 11: MGMP Collaboration*
3	**Transformation:** The first environmental science collaboration conducted by teachers from the three subjects.
4	**Worldview:**

No	Holon 5 Collaborative Development
	Teachers are at the forefront of processing and providing learning materials to students. With real education in the mangrove forest, MGMP will find it easier to understand the benefits of the mangrove forest ecosystem and the environmental issues related to global climate change.
5	**Owners:** Indonesia
6	**Environmental:** Stakeholders related to MGMP training and environmental education concerning global climate change.

Table 7. Holon 7, Biology Teaching Module Phase E (Grade 10)

No	Holon 7 Biology Teaching Module Phase E (Grade 10)
1	**Customers:** Senior High School
2	**Actors:** Gadis Antariksa Icon.
3	**Transformation:** Designing teaching modules related to the mangrove ecosystem in the form of a 3D video.   *Figure 12. Biology Teaching Module* *Phase E.*
4	**Worldview:** Learning materials follow

No	Holon 7 Biology Teaching Module Phase E (Grade 10)
	contemporary developments and utilize language that is easy to understand.
5	**Owners:** Indonesia
6	**Environmental:** Stakeholders related to education and environmental issues concerning global climate change.

Table 8. Holon 8, Greenhouse Sains for Education

No	Holon 8 Greenhouse Sains for Education
1	**Customers:** Indonesia
2	**Actors:** Gadis Antariksa Icon
3	**Transformation:** The greenhouse aims to enhance students' knowledge of the types of plants in the mangrove forest and to train students to think critically about science and technology.  *Figure 13. Greenhouse for Education*
4	**Worldview:** Students can create products or technologies for future food security.
5	**Owners:** TWA Angke Kapuk
6	**Environmental:** Stakeholders related to MGMP training and environmental education concerning global climate change.

Tabel 9: Annual Semester Learning Plan (RPS)
Program

Subject: Biology.
Phase/Class/Semester: E, Class X
School year: 2024/2025
Curriculum: National Independence
Allocation Time: 2x45

No	Material (Achievment Learning Subject)
1	Participants will understand the process of

No	Material (Achievment Learning Subject)
	classifying living creatures that exist in the mangrove forest. **1.1 Classsification of Living Things** 1.1.1 Grouping living things in the mangrove forests. 1.1.2 The roles of living things in the mangrove forests. **1.2 Biodiversity** 1.2.1 Understanding diversity life in mangrove forest. 1.2.2 Levels of diversity in mangrove forest. 1.2.3 Biodiversity in the mangrove forests. 1.2.4 Benefits of diversity in the mangrove forests. 1.2.5 Conservation of biodiversity in the mangrove forests.
2	Participant will understamd the process of classifying living creatures that exist in the mangrove forests. **2.1 Living Things in the Ecosystem** 2.1.1 Understanding the mangrove forest ecosystem. 2.1.2 Interaction between components of the mangrove forest ecosystem. 2.1.3 Human activities that cause environmental changes and their solution.

Source: Based on the latest CP 7 June 2024 and the Merdeka curriculum package book.

Tabel 10: Youth Scientific Group (KIR) Work Program of SMAN 66 South Jakarta

No	Material (Achievment Learning Subject)
1	**SPEKTRA (Expert Seminar and Applied Science Studies):** Programs designed to provide in-depth scientific insights to students through seminars led by experts in the field of science. The speakers deliver material aimed at understanding scientific problems related to environmental issues and global climate change, particularly concerning mangrove ecosystems. The purpose of this activity is to enhance KIR members' critical thinking skills.

No	Material (Achievment Learning Subject)
	Gadis Antariksa Icon Role: Provide material on current environmental learning issues, improve understanding, and increase KIR members' concern regarding global climate change, enhancing mitigation actions.
2	**SOLIENCE Adventures:** A program designed to broaden the horizons of Youth Scientific Group (KIR) members regarding science and technology through real educational experiences. **Gadis Antariksa Icon Role:** Provide innovative learning related to mangrove ecosystems, increasing KIR members' understanding of the mangrove ecosystem and its relation to global climate change.

Source: KIR Work Program of SMAN 66 South Jakarta

After conducting the CATWOE analysis to identify the main problems in the system being analyzed, the next stage in the SSM is to build a conceptual model. A conceptual model is designed to describe the relationships between the main activities required to achieve the desired changes as defined through the perspective of stakeholders at the CATWOE stage. The conceptual model acts as a framework for thinking that maps the process of input, transformation, and output between activities, serving as a basis for comparing models in SSM. This is an important stage that aims to describe the relationships between activities, roles, and processes in complex and unstructured systems. Conceptual models not only serve as a problem mapping tool but also as a basis for identifying relevant solutions by systematically and participatively involving various stakeholders. The conceptual model can be seen in Figure 17:

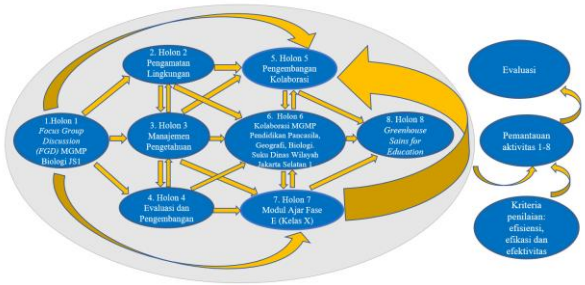

Figure 14. Conceptual Model

Conceptual Model Development Process

After *Root Definition (RD)* established, the next step is to build a conceptual model based on the definition. The *RD* The Conceptual Model serves as a graphical representation of *RD* perspective, which describes the relationship between activities and their respective roles each party in achieving the goals. In this study, support for the action's global climate change mitigation action in ecosystem learning innovation mangroves through KIR, with the Gadis Antariksa Icon strategy, can be seen in Table 11:

Tabel 11: Conceptual Model Development Process (Conceptual Model Contribution)

No	Model Activities Conceptual
1	Analyze the main problem in learning about mangrove ecosystems, such as budget, policy, and government regulations through Focus Group Discussion (FGD). **Real World System (Current Practice):** Delivered by concerned parties, specifically the deliberation of subject teachers (MGMP) Biology JS1. **Device:** Discussion interaction and questionnaire related to natural resource sources and impacts from global climate change. **Action:** Collaboration among stakeholders to realize mitigation actions for global climate change. **Contribution Model:** Responding to questionnaires via visits to several high schools in the South Jakarta region to observe the environment and participant behavior during classroom learning.
2	Determine internal and external knowledge sources related to the mangrove ecosystem through environmental observation and feedback from participants, followed by document analysis, interviews, and questionnaires to gather data. **Real World System (Current Practice):** Locations available at SMAN 66, facilitating environmental observation studies. **Device:** Model prediction requests for learners in action related to innovative learning about mangroves. **Action:** There has not yet been a visit to SMAN 66 from stakeholders interested in education related to the mangrove ecosystem. **Contribution Model:** Recommendations and improvements developed with the Gadis Antariksa Icon strategy to identify, analyze, and develop mitigation actions for global climate change in innovative

No	Model Activities Conceptual
	learning about the mangrove ecosystem at the senior high school level.
3	Develop a collaboration model through seminars related to deep mangrove ecosystem actions for global climate change mitigation, ensuring that knowledge management is understandable and efficiently stored in a systematic manner. **Real World System (Current Practice):** There is innovative learning related to the mangrove ecosystem through KIR seminars at SMAN 66. **Device:** Collaboration model and optimization in actions for global climate change mitigation related to innovative learning about the mangrove ecosystem with the Gadis Antariksa Icon strategy. **Action:** The government has not yet utilized the collaboration model for global climate change mitigation actions in innovative learning about the mangrove ecosystem through KIR. **Contribution Model:** The formation of a systematic approach in implementing innovative learning about the mangrove ecosystem, with the Gadis Antariksa Icon strategy becoming an innovative solution to face global climate change through KIR SMAN 66.
4	Evaluate and collaborate to support global climate change mitigation actions related to the mangrove ecosystem with the Gadis Antariksa Icon strategy. **Real World System (Current Practice):** Analysis of stakeholder interests regarding global climate change mitigation actions for mangrove forests through KIR. **Device:** Management system based on data, model, and knowledge. **Action:** Stakeholders have not yet utilized global climate change mitigation actions for mangrove forests through KIR. **Contribution Model:** The

No	Model Activities Conceptual
	Gadis Antariksa Icon strategy is capable of designing effective global climate change mitigation actions in innovative learning related to the mangrove ecosystem. Collaboration between KIR SMAN 66, teachers, and parents in innovative learning related to the mangrove ecosystem, with the Gadis Antariksa Icon strategy.
5	Design collaborative development to enhance global climate change mitigation actions related to the mangrove ecosystem with the Gadis Antariksa Icon strategy. **Real World System (Current Practice):** Analysis of stakeholder interests regarding global climate change mitigation actions for mangrove forests through KIR. **Device:** Management system based on data. **Action:** Stakeholders have not yet utilized information systems for global climate change mitigation actions for mangrove forests through KIR. **Contribution Model:** The Gadis Antariksa Icon strategy is capable of developing sustainable global climate change mitigation action models related to the mangrove ecosystem.
6	Education collaboration among Pancasila, Biology, and Geography teachers in the MGMP JS1 framework to promote scientific collaboration related to the mangrove ecosystem with the Gadis Antariksa Icon strategy. **Real World System (Current Practice):** Analysis of stakeholder interests regarding global climate change mitigation actions for mangrove forests through MGMP. **Device:** Management system based on data, model, and knowledge. **Action:** Stakeholders have not yet conducted MGMP collaboration as a global climate change mitigation action for mangrove forests.

No	Model Activities Conceptual
	Contribution Model: The Gadis Antariksa Icon strategy is capable of designing sustainable collaboration.
7	Develop Biology teaching modules for Phase E (Grade X) to enhance the quality of education related to the mangrove ecosystem. **Real World System (Current Practice):** Analysis of the curriculum and learning achievements related to the mangrove ecosystem and its connection to climate change. **Device:** 3D video animation of the mangrove ecosystem and its connection to climate change. **Action:** Stakeholders have not yet utilized the Biology teaching module for Phase E (Grade X) in the form of a 3D video related to the mangrove ecosystem. **Contribution Model:** The Gadis Antariksa Icon strategy is capable of designing innovative and sustainable Biology teaching modules for Phase E (Grade X) related to the mangrove ecosystem.
8	Establish a Science Greenhouse for Education to enhance innovative learning and critical thinking related to the mangrove ecosystem. **Real World System (Current Practice):** Analysis of the KIR SMAN 66 South Jakarta work program. **Device:** Designing and building a greenhouse as a means of science education in the Mangrove TWA Angke Kapuk. **Action:** Stakeholders have not yet designed a greenhouse as a science education facility in TWA Angke Kapuk. **Contribution Model:** The Gadis Antariksa Icon strategy is capable of designing a greenhouse as a sustainable learning resource related to the mangrove ecosystem.

Tabel 12: Validation

No	Validation
1	**Activities:** Focus Group Discussion (FGD) MGMP Biology JS1. Increase knowledge regarding budget policies and regulations. **Efficiency:** Budget efficiency and time in discussing internal environmental improvement issues, enhancing the efficiency of blending or aligning perceptions. **Efficacy:** Improved quality analysis towards global climate change mitigation actions related to mangrove ecosystem education for participants. **Effectiveness:** Finding solutions to educational problems related to real education in mangrove forests in the context of global climate change mitigation actions.
2	**Activities:** Environmental Observation at SMAN 66. Increase knowledge about the school environment and student behavior. **Efficiency:** Efficiency analysis of behavior and related environmental knowledge. **Efficacy:** Increased understanding of environmental behavior among students and participants. **Effectiveness:** Enhanced understanding of behavior and knowledge among participants.
3	**Activities:** Knowledge Management. Increased knowledge through the KIR Seminar related to mangrove ecosystems with the Gadis Antariksa Icon strategy. **Efficiency**: Efficiency analysis related to knowledge of the mangrove ecosystem. **Efficacy:** Improved quality of education related to knowledge of the mangrove ecosystem through KIR with the Gadis Antariksa Icon strategy. **Effectiveness:** Quality improvement in education influenced by learning innovations through KIR.
4	**Activities:** Evaluation and Development. Increased global

No	Validation
	climate change mitigation actions in innovative learning about mangroves with the Gadis Antariksa Icon strategy. **Efficiency:** Deep learning innovations increase actions for climate change mitigation through real education about mangroves. **Efficacy:** Added value to the quality of learning and critical thinking with the Gadis Antariksa Icon strategy. **Effectiveness:** The predicted success percentage will improve the quality of education related to the mangrove ecosystem through KIR.
5	**Activities:** Development Collaboration. Improvement of the collaboration model among stakeholders in innovative learning related to mangrove ecosystems with the Gadis Antariksa Icon strategy. **Efficiency:** Time and budget efficiency in implementing innovative educational learning about mangroves as a global climate change mitigation action. **Efficacy:** Improved quality of education through innovative learning related to the mangrove ecosystem in the context of global climate change mitigation actions with the Gadis Antariksa Icon strategy. **Effectiveness:** The success percentage of this model development will increase creativity and concern among participants for global climate change mitigation.
6	**Activities:** Development Collaboration. Improvement of the collaboration model among stakeholders in innovative learning related to mangrove ecosystems with the Gadis Antariksa Icon strategy. **Efficiency:** Time and budget efficiency in implementing innovative educational learning about mangroves as a global climate change mitigation action. **Efficacy:** Improved quality of education through innovative learning related to the mangrove ecosystem in the context of global

No	Validation
	climate change mitigation actions with the Gadis Antariksa Icon strategy. **Effectiveness:** The success percentage of this model development will increase creativity and concern among participants for global climate change mitigation.
7	**Activities:** Teaching Models for Phase E (Grade X). Designing teaching modules related to the mangrove ecosystem. **Efficiency:** Time efficiency related to learning about the mangrove ecosystem. Budget efficiency for educational visits to mangrove forests. **Efficacy:** Increased knowledge and concern among participants through innovative learning related to the mangrove ecosystem in the form of a 3D video with the Gadis Antariksa Icon strategy. **Effectiveness:** The success percentage of learning achievements through the Phase E (Grade X) teaching module in the form of a 3D video can be implemented nationally to improve stakeholder performance.
8	**Activities:** Greenhouse Science for Education. Designing innovative learning by building a greenhouse in the Mangrove TWA Angke Kapuk. **Efficiency:** Time efficiency and budget considerations in studies, such as processing products from mangrove plants in Indonesia. **Efficacy:** Increased creativity and critical thinking related to science and technology, enabling the creation of products for future food security. **Effectiveness:** The success percentage of the KIR program can be implemented nationally to improve stakeholder performance.

Questionnaire Data Collection Results

Results of the Questionnaire for Teachers in DKI

Based on the analysis using the t-test with a significance level (alpha) of 0.05, the average pre-test score was 42.47, while the average post-test score was 46.37. This indicates an increase in the average score of 9.18%, demonstrating a positive improvement following the intervention or treatment provided. The

obtained p-value was 0.0007, indicating a significant difference between the pre-test and post-test scores.

The validity of the questionnaire instrument showed improvement, with an average validity of 0.7099 for the pre-test and 0.8561 for the post-test. The reliability of the instrument exhibited very good internal consistency, with a pre-test reliability value of 0.8897 and a post-test value of 0.9588. Therefore, there is a significant difference between the pre-test and post-test scores, indicating an improvement in results after the intervention. The questionnaire instrument used is valid and reliable in both measurements, as illustrated in Figure 15.

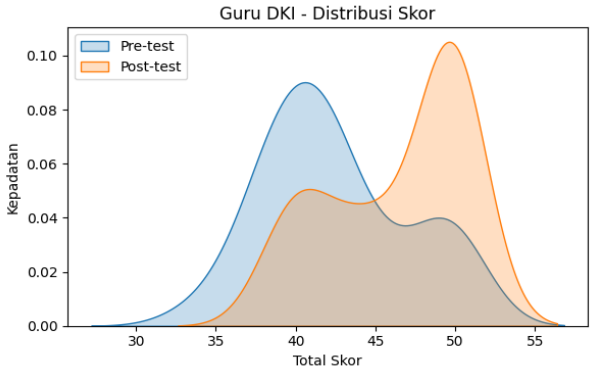

Figure 15. Results of the Questionnaire for Teachers in DKI

Results of the Questionnaire for Students of SMAN 66 South Jakarta

Based on the analysis using the t-test with a significance level (alpha) of 0.05, the average pre-test score was 41.73, while the average post-test score was 46.33. This resulted in an increase in the average score of 11.02%. The p-value was 0.000 ($p < 0.05$), indicating a significant difference between the pre-test and post-test scores.

The validity of the questionnaire instrument improved from an average of 0.6102 in the pre-test to 0.749 in the post-test, demonstrating an enhancement in the quality of the instrument's validity after the intervention, making it more relevant and capable of measuring variables more accurately. The reliability values were 0.8128 for the pre-test and 0.9121 for the post-test, indicating very good measurement consistency. Thus, there is a significant difference between the pre-test and post-test scores, showing an improvement in results after the intervention. The questionnaire instrument used is valid and reliable in both measurements, as shown in Figure 16.

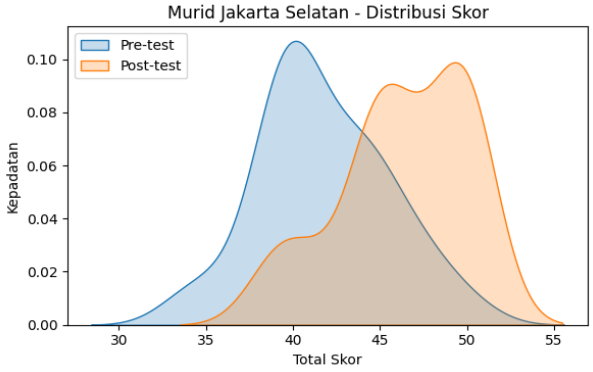

Figure 16. Results of the Questionnaire for Students of SMAN 66 South Jakarta

Results of the Questionnaire for Students of SMA IP Yakin West Jakarta

Based on the analysis of the questionnaire using the t-test with a significance level (alpha) of 0.05, the average pre-test score was 39.6, while the average post-test score was 46.1. This resulted in an increase in the average score of 16.41%. The p-value was 0.0002, indicating a significant difference between the pre-test and post-test scores.

The validity of the questionnaire instrument in the pre-test had an average of 0.7938, while in the post-test it slightly decreased to 0.7244, but it still remained within the valid category. The reliability of the instrument was classified as very good, with values of 0.9317 for the pre-test and 0.8811 for the post-test, indicating high measurement consistency. Therefore, there is a significant difference between the pre-test and post-test scores, indicating an improvement in results after the intervention. The questionnaire instrument used is valid and reliable in both measurements, as illustrated in Figure 17.

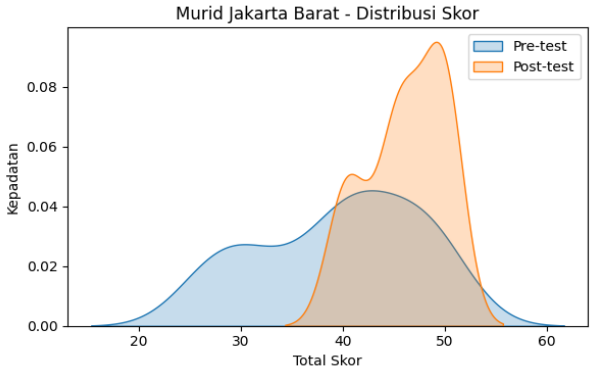

Figure 17. Results of the Questionnaire for Students of SMA IP Yakin West Jakarta

Results of the Questionnaire for Students of SMAN 15 North Jakarta

Based on the analysis of the questionnaire using the t-test with a significance level (alpha) of 0.05, the average pre-test score was 43.33, while the average post-test score was 48.33. This resulted in an increase in the average score of 11.54%. The obtained p-value was 0.000 ($p < 0.05$), indicating a significant difference between the pre-test and post-test scores.

The validity of the questionnaire instrument improved from an average of 0.6033 in the pre-test to 0.6366 in the post-test, indicating an enhancement in the quality of the instrument's validity after the intervention, making it more relevant and capable of measuring variables more accurately. The reliability of the instrument increased from 0.801 in the pre-test to 0.8386 in the post-test, indicating very good measurement consistency. Therefore, there is a significant difference between the pre-test and post-test scores, indicating an improvement in results after the intervention. The questionnaire instrument used is valid and reliable in both measurements, as shown in Figure 18.

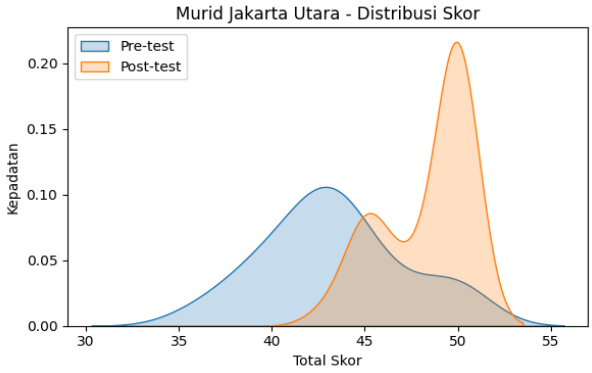

Figure 18 Results of the Questionnaire for Students of SMAN 15 North Jakarta

CONCLUSION

Based on the analysis results, it can be concluded that there is a significant increase in knowledge and attitudes among participants after the educational interventions were administered. The instruments used have proven to be valid and reliable, ensuring that the data obtained is trustworthy. The interventions provided are effective in enhancing knowledge, which is a critical factor in improving the quality of education at the secondary level.

The Knowledge Capture (KC) model can identify and analyze complex problems related to participants' understanding of the mangrove ecosystem through the Gadis Antariksa Icon strategy. The KC model is designed to facilitate mitigation actions for global climate change through innovative learning about the mangrove ecosystem. This model not only supports knowledge and awareness in documented form but also fosters collaboration among various educational stakeholders, including teachers and educational organizations. It includes the design of interactive teaching models and the development of educational resources, such as a Greenhouse Science initiative, as part of the Gadis Antariksa Icon strategy to enhance global climate change mitigation efforts. This can serve as a decision-making strategy for stakeholders at various levels. The KC model, based on the SSM approach through the implementation of the Gadis Antariksa Icon movement, has proven to be effective, efficient, and sustainable, thereby improving the quality of mangrove ecosystem education as a global climate change mitigation action.

SUGGESTIONS

1. **Development of Learning Materials:** It is recommended to develop interactive and easily understandable learning materials to enhance students' knowledge sustainably.
2. **Training for Educators:** Conduct training sessions for educators to improve their ability to deliver material effectively and engagingly.
3. **Periodic Evaluation:** Regular evaluations should be conducted using pre-tests and post-tests to monitor participants' knowledge progress.
4. **Further Research:** Future research can explore additional factors that may influence knowledge enhancement, such as learning motivation and various teaching methods.
5. **Application in Diverse Contexts:** This method should be applied in different regions or educational settings to test its effectiveness in various contexts.
6. **Data Analysis Development:** This research can be expanded at the national level using the System Dynamics method to obtain quantitative model validation. The questionnaire data can then be processed using a system dynamics simulation model, utilizing software tools to analyze causal relationships from the captured data, producing behaviors consistent with real-world systems.

ACKNOWLEDGMENT

We would like to express our gratitude to the Principal of SMAN 66 South Jakarta for providing us the opportunity to conduct research involving the KIR extracurricular. We also extend our thanks to Al Azhar University Indonesia for facilitating this research. Additionally, we acknowledge the support of MGMP Pancasila, Biology, and Geography, South Jakarta Education Sub-department Area 1, TWA Angke Kapuk, Mangrove PIK, SMA IP Yakin West Jakarta, SMAN 15 North Jakarta, and all parties who have helped in this research.

REFERENCES

Andy, S. B., et al. (2022). Strategy to increase awareness and concern for mangrove ecosystems in students of SDN 54 and SDN 206 in Pallameang Village, Mattiro Sompe District, Pinrang Regency. *Journal Dynamics Service, 8*(1), 41-31. http://journal.unhas.ac.id/index.php/jdp/article/view/22605

Batari, F. (2024). Mahasiswi magister universitas UAI luncurkan Gadis Antariksa. *Jpnn*. https://m.jpnn.com/news/mahasiswi-magister-universitas-uai-luncurkan-gadis-antariksa

Budi, V. (2024). Membangun mental peduli lingkungan dalam rangka peringatan hari mangrove sedunia. *Koran Jakarta*. https://koran-jakarta.com/membangun-mental-peduli-lingkungan-dalam-rangka-peringatan-hari-mangrove-sedunia

Elvianasti, M., Diliarosta, S., & Anggana, P. (2022). Understanding of high school biology teachers at DKI Jakarta mover schools towards the ethnoscience approach to the independent curriculum. *Journal of Education and Culture, 7*(2), 153-163. https://jurnaldikbud.kemdikbud.go.id/index.php/jpnk/article/view/2993/611

Farhana, G., & Cholimah, N. (2024). Pancasila student profile strengthening project as an effort to improve early childhood character. *Obsesi Journal: Early Childhood Education, 8*(1), 137-148. https://doi.org/10.31004/obsesi.v8i1.5370

Fitria, A., & Dwiyanto, G. (2021). Mangrove ecosystem and global warming mitigation. *EMS: Journal of Ecology, Society & Science, 2*(1), 2720-9717. https://jurnal.fst.uinjambi.ac.id/index.php/Jssit/article/view/49/13

Hadi, W. P., Rendy, D. B., Putera, A., Nurmegawati, S., Abidin, L., & Putri, M. M. (2025). Optimization of mangrove as natural dye for batik tulis Tanjung Bumi Madura to train students' green economy entrepreneurship. *Journal of Community Service and Empowerment*.

Hajunilato, T., & Sumaryanti, S. (2024). Strategy strengthening student nationalism based on culture school in senior high school country 1 Belitang. *Journal of Education, 8*(1), 37-44. http://journal.unismuh.ac.id/index.php/

Handono. (2024). The development of popular scientific book mangrove diversity based on contextual learning material of biodiversity in senior high school. *Journal of Natural Science and Learning, 3*(1), 1-14. https://journalng.uwks.ac.id/jnsl/article/view/117/121

Mandar, A., Yunus, W. M., Asfar, A., & Mastali, M. (2024). Development capacity of Mastali Madu Group in maintaining the mangrove ecosystem in Purnama Village, Dumai City. *Indonesian Environmental Dynamics, 11*(2), 85-90. https://dli.ejournal.unri.ac.id/index.php/DL

Maydita, P. (2024). Mahasiswa magister Al Azhar Indonesia luncurkan 'Gadis Antariksa.' *Radio Republik*

Indonesia. https://www.rri.co.id/daerah/858942/mahasiswa-magister-al-azhar-indonesia-luncurkan-gadis-antariksa

Purnama Putra, E. (2024). Peluncuran Gadis Antariksa untuk penyelamatan mangrove mendapat apresiasi. *Republika*. https://news.republika.co.id/berita/shfcsl484/peluncuran-gadis-antariksa-untuk-penyelamatan-mangrove-mendapat-apresiasi

Rahmadi, M. T., et al. (2023). Threats to mangrove ecosystems and their impact on coastal biodiversity: A study on mangrove management in Langsa City. *Indonesian Journal of Earth Sciences, 3*(2), 1-14. https://journal.moripublishing.com/index.php/injoes

Setiawan, A., Suyanta, & Widowati, A. (2024). Utilization of mangrove ecotourism as a science learning resource for junior high school students. *Journal of Science Education Research, 10*(03), 1205-1212. https://doi.org/10.29303/jppipa.v10i3.5531

Simbolon, T. G. L., et al. (2024). Impact analysis and control strategy of coastal mangrove damage in North Sumatra. *Journal of Public Relations, 2*(2), 10-20. https://doi.org/10.59581/jrp.widyakarya.v2i2.3029

Sukmana, Y. (2024). Manfaat ekosistem mangrove bagi ekonomi masyarakat pesisir. *Kompas.com*. https://money.kompas.com/read/2024/08/02/221455826/manfaat-ekosistem-mangrove-bagi-ekonomi-masyarakat-pesisir

Sucipto. (2024). Peringati hari mangrove sedunia, Gadis Antariksa ajak generasi muda peduli lingkungan. *Sindonews*. https://daerah.sindonews.com/read/1423987/171/peringati-hari-mangrove-sedunia-gadis-antariksa-ajak-generasi-muda-peduli-lingkungan-1722067637

Sucipto. (2024). Biopropeksi blue carbon mangrove mampu lindungi bumi dari perubahan iklim. *Sindonews*. https://daerah.sindonews.com/read/1514175/171/bioprospeksi-blue-carbon-mangrove-mampu-lindungi-bumi-dari-perubahan-iklim

Sucipto. (2024). Pentingnya pendidikan lingkungan dalam menghadapi perubahan iklim. *Sindonews*. https://nasional.sindonews.com/read/1404293/15/pentingnya-pendidikan-lingkungan-dalam-menghadapi-perubahan-iklim-1719461179

Tiffani, K., Kustati, M., Amelia, R., Mardianto, M., & Nurhasanah, N. (2024). Coaching creativity students through extracurricular activities group scientific teenager (KIR) in MAN 2 Kuantan Singigi. *Journal of Community Service Public and Research Education, 2*(4), 432-443. https://jerkin.org/index.php/jerkin/article/view/306/196

Thank You, A., Idrus, A., Mahrus, R., & Raksun, A. (2024). Utilization of mangrove environment as a science learning resource for teachers and students of Telage Bagik Middle School, Ketapang Raya Village, East Lombok. *Journal of Community Service for Master of Science Education, 7*(1), 330-335. https://doi.org/10.29303/jpmpi.v7i1.8235

Yunita, S., Ginting, A. C., Naila, M. A., & Ardi, M. (2024). Analysis students' understanding of insight Nusantara (geopolitics) and the relation with love for the homeland in the era globalization. *Innovative: Journal of Social Science Research, 4*(2), 757-764. https://jinnovative.org/index.php/Innovative/article/view/9503/6500