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# Environmental Problem-Solving Learning Model with Geographic Information System-Based Learning Media

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**ABSTRACT**

In the era of environmental crises and human challenges amidst rapid technological advancements, geography is an increasingly urgent discipline in comprehending the spatio-temporal dimensions of environmental sustainability. Therefore, effective, innovative, and collaborative implementation of geography learning in schools is essential. This goal can be achieved by emphasizing students' critical thinking, problem-solving, and spatial thinking skills. The researcher designed an environmental problem-solving learning model to address this need. The environmental problem-solving learning model embraces problem-based learning focused on contextual environmental issues. This research aims to analyze the effectiveness of implementing the environmental problem-solving learning model with GIS-based learning media. The study employs an experimental design that utilizes a one-group pretest-posttest approach. The study group in this research was purposively selected, including 33 students from an urban area school, SMA Negeri 3 Semarang, and 35 students from a rural area school, SMA Negeri 1 Beringin. Data collection involved test methods, observations, and literature review. Qualitative data analysis was performed using an interactive method, while quantitative data analysis employed descriptive statistical analysis and a one-paired sample t-test. This research indicates that the environmental problem-solving learning model with GIS-based learning media effectively improves student learning outcomes. This model promotes active, student-centered learning, encourages collaboration and cooperation among students, and positions students as the primary subjects in the learning process. Furthermore, it fosters the development of critical thinking and problem-solving skills in students. The findings of this research underscore the potential of the environmental problem-solving learning model to be implemented in geography education. Various stakeholders play a crucial role as change agents in promoting innovative transformations in geography learning, including encouraging the realization of GIS-based environmental problem-solving models in various educational contexts.

## 1. INTRODUCTION

Currently, two phenomena are on the rise, significantly impacting life on our planet and carrying long-term consequences for society and the environment. Climate change, environmental degradation, and biodiversity loss contribute to ecological and social crises. Simultaneously, humanity is experiencing constant technological advancements, marking a transition toward a digital society [1]. Amid environmental and human crises amid rapid technological advancement, geography emerges as an increasingly urgent discipline. It provides a means to comprehend our progressively complex and insecure world. The geographical tradition, centering on human and environmental themes, offers a methodological foundation for addressing sustainability issues. Geography-related approaches to dynamics, complexity, and interactions support understanding the spatio-temporal dimensions of environmental sustainability [2].

Geography is an essential life skill that enables students to cultivate profound knowledge and understanding of the factors influencing the world's current state. It explores the intricate interrelationships among humans, places, and the environment across diverse locations and periods [3]. In the 21st century, the relevance of geography has heightened, being a place-based science that fosters high-level thinking skills and decision-making abilities [4-6]. Geography is a crucial component of economic and social processes [7], aiming to educate students about practical skills applicable to solving complex human problems.

The urgency of geography has driven it to become a mandatory subject in many countries, whether as a separate subject or integrated into other curricula, from primary education and secondary education to universities [8].

Furthermore, geography's distinctive characteristics and heightened urgency form the foundation for advocating that geography learning should not heavily emphasize memorization or burden students with encyclopedic and statistical information. Instead, it should guide students beyond the classroom walls and foster analytical thinking patterns [9] and also prioritize high-order thinking skills (HOTS) [10]. Geography learning patterns should not merely transfer knowledge to students but also allow them to feel, observe, analyze, discover, and conclude [11]. Therefore, in geography learning, students are expected to comprehend the relationships among various aspects of the discipline, draw insights from previously discussed concepts and theories, and connect them to real-world situations [12]. Furthermore, Nagel [13] has highlighted that geography learning in the 21st century should prompt students to perceive and address problems from a geographic perspective, particularly a spatial one.

The importance of meaningful geography learning is increasingly evident due to the various obstacles that geography education currently faces. One significant challenge is the low learning outcomes of students and a tendency towards teacher-centered learning [14]. Artvinli [15] noted that a significant impediment in geography education is the reluctance of geography teachers to embrace technological advancements, including GIS. However, GIS has yet to be widely utilized in geography education due to teachers' reported lack of knowledge regarding GIS applications [16, 17]. Furthermore, geography learning often relies on memorization processes and is centered around textbooks [18]. Compounding the issue, high school students frequently perceive geography as boring, uninteresting, or challenging [19].

To address these challenges, there is a need for innovations in various learning system components, including models, methods, media, and teacher competencies. Effective learning methods directly impact student learning outcomes [20]. This should be a severe concern for institutions that provide geography education in various countries, as they are responsible for producing professional teachers who teach geography in different schools. Educators' diverse teaching methods and strategies can facilitate students' engagement in problem-solving processes, comprehension of theories, and application of knowledge and skills to address challenges [21]. Integrating technology into education transforms the educational process, enhancing the effectiveness of teaching various subjects [22, 23], making learning more enjoyable [24], and fostering a more interactive learning environment [25]. Moreover, teachers play a pivotal role in driving change within schools. It is essential to recognize that no curriculum possesses magical powers; the true transformative force in education lies in the dynamic relationship between teachers and students [26].

The researcher developed the environmental problem-solving learning model to build on the aforementioned challenges. This model embraces the concept of problem-based learning, explicitly concentrating on contextual environmental issues. While this concept may not be entirely novel, as geography has a tradition of group work widely employed in PBL [12], the environmental problem-solving learning model aims to extend and refine its application. Geographers have historically integrated problem-based and project-based learning with place-based learning, emphasizing environmental sustainability [27-30].

Numerous studies have demonstrated the effectiveness of problem-based learning (PBL) models. PBL, rooted in social constructivism concepts, stands out as a method to promote active learning [31]. This approach initiates with real-world problems or issues relevant to students [32], thereby enhancing their abilities in self-directed learning, critical thinking, and problem-solving [33-36]. Additionally, PBL contributes to developing teamwork skills, leadership, and collaborative learning [37-41].

Integrating problem-solving with environmental topics in the environmental problem-solving model is grounded in the close relationship between geography and environmental sustainability [42-44]. Geography is often called the science of sustainability [45, 46]. Geography explores the intricate relationship between humans and the environment [47-49]. This inherent connection makes geography well-suited for advancing education aligned with sustainable development goals (ESD) [50-53].

Based on the preceding explanation, several issues can be identified. The worldwide environmental problems present challenges for geography as a field that teaches about the relationship between humans and the environment. These challenges need to be addressed in more innovative ways. Geography is still often implemented in a teacher-centered manner, perceived as a subject focused on memorization, and rarely utilizes geospatial technology, which leads to low student learning outcomes. Therefore, innovative teaching models and learning media are needed to enhance students' skills and learning outcomes.

According to the problems and potentials described, this research will implement the environmental problem-solving learning model with GIS-based learning media, specifically utilizing Google Earth Engine. Geospatial technology is highly effective, as it encourages students to actively engage in the learning process, assuming a central and crucial role in 21st-century education [54-56]. Recognized for its immense educational potential, geospatial technology has been highlighted as a valuable tool for achieving educational goals [57]. Labianca [58] emphasized that GIS can support the process of education for sustainable development goals. The environmental problem-solving teaching model using GIS is an innovation in geography education. It combines problem-based learning, environment-based learning-which has not been widely implemented-and GIS as an interactive learning medium. Traditionally, GIS has often been taught as a separate subject rather than being integrated as a medium to study geography topics comprehensively. Against this backdrop, the research aims to analyze the effectiveness of implementing the environmental problem-solving learning model with GIS-based learning media.

## 2. METHOD

### 2.1 Research design

This study adopts an experimental research design with the primary objective of developing and assessing the effectiveness of the environmental problem-solving learning model using GIS-based media. The research methodology employs a one-group pretest and posttest design, facilitating comparing conditions before and after the experiment.

### 2.2 Study groups

The study group, comprised of students from two distinct schools characterized by varying geographic, social, and cultural conditions, was purposefully selected in this research. The deliberate inclusion of two different study groups serves the dual purpose of generating more diverse findings and enhancing the overall robustness of the research outcomes. The chosen schools for this research are:

1. SMA Negeri 3 Semarang: Located in the center of Semarang City, Central Java Province, this school is in a densely populated metropolitan environment with a modern lifestyle.
2. SMA Negeri 1 Beringin: Positioned in Semarang Regency, Central Java Province, this school is set in a rural environment marked by agricultural patterns and is distant from urban centers.

The selection of these two study groups considers various input conditions, encompassing student characteristics and backgrounds, physical and social school environments, school facilities, and the environmental challenges students face in their respective living areas. Both study groups have given their consent and expressed their willingness to participate in the experiment conducted by the researcher. The school administration has also granted permission to conduct research activities.

The study group comprises 68 high school students from grade 10, with a breakdown of 33 students from the urban areas school (SMA Negeri 3 Semarang) and 35 from the rural areas school (SMA Negeri 1 Beringin). SMA Negeri 3 Semarang was chosen because it is one of the top-quality high schools in Semarang City. Meanwhile, SMA Negeri 1 Beringin was selected because it is a rural school with a challenging geographical location and accessibility, thus having more limited resources than SMA Negeri 3 Semarang. Both study groups were selected purposively from classes with the highest geography grades in their respective schools. These two study groups will be experimental classes, implementing the environmental problem-solving model with Google Earth Engine as the learning media.

The selection of schools with two different geographical conditions is also based on several previous studies. Echazarra and Radinger [59] and Tasema and Braeken [60] stated that students in urban areas have better educational support opportunities compared to those in rural areas, such as economic status and school resources, and they can take advantage of this support. Conversely, in rural areas, due to their remote locations, there often needs to be more social services and resources. For instance, rural schools have fewer qualified and competent teachers and need more resources to support effective learning [61-63].

One of the most crucial resource elements is the availability of technology and the teachers' ability to use technology to support learning [64]. Several studies indicate that there is still a gap between urban and rural schools regarding technology. These include differences in teachers' technological literacy [65], differences in students' technological abilities [66], the frequency of technology use in teaching by teachers [67], and training in the use of ICT for teachers [68]. These disparities impact the innovation and variety of teaching strategies typically employed in urban schools compared to rural schools [69]. The difference prompted the researcher to select study areas in two different schools, namely an urban school and a rural school.

### 2.3 Experimental process

The experiment in each study group in this research spanned three weeks, with each week comprising three instructional hours. The experimental process encompassed three main phases: the pretest phase, the implementation of learning using the environmental problem-solving model with Google Earth Engine as the medium, and the posttest phase. In the first week, the learning activities included a pretest, followed by the initial stage of the treatment, which focused on introducing concepts, forming groups, and explaining student tasks. In the second week, the learning activities centered on group activities for discussion and exploration. In the third week, the learning activities focused on presentations, discussions, knowledge construction, and reflection, ending with a posttest. To control for confounding variables or bias between both study groups, both study groups underwent the learning process employing the same model and medium. Both study groups' learning scenarios and steps were carried out using the same mechanism. The distinguishing factor between the two groups was utilizing case studies tailored to the environmental conditions and issues specific to the student's residential areas to ensure a contextualized and relevant implementation.

The improvement in students' learning outcomes analyzed from their pretest and posttest scores indicates learning effectiveness in this experimental research. This is in line with studies by Aristin et al. [70], Rahmatullah [71], Rini et al. [72], and Tai and Yuen [73], which emphasize that one of the crucial indicators in analyzing learning effectiveness is students' learning outcomes. Students' learning outcomes serve as an indicator to assess the achievement of learning objectives [74] and evaluate the quality of teaching provided [75]. Students' learning outcomes are measured using questions formulated based on Bloom's Taxonomy, focusing on the analysis, evaluation, and creation levels (C4-C6) [76].

### 2.4 Data collection

This research employs a combination of primary and secondary data sources. Primary data is acquired through direct data collection in the field, while secondary data is gathered through a literature review of theories and previous research findings published in scientific journals. Two main methods are utilized for primary data collection: observation and testing. Observation is conducted to gather data related to the implementation of learning using the environmental problem-solving model. Meanwhile, testing methods are employed to measure students' learning outcomes before and after the experiment by administering pretest and posttest assessments. The pretest and posttest questions are structured in a multiple-choice format, each comprising 25 items. The scoring system attributes 4 points for each correct answer and 0 points for each incorrect answer. Before being used, the pretest and posttest instruments were validated for content validity by experts and practitioners in the field of geography education and were deemed suitable for use.

The literature review is employed to analyze the development of the environmental problem-solving learning model. This is crucial because the environmental problem-solving learning model is not developed arbitrarily; instead, it undergoes systematic literature review stages, considering various theories and findings from previous studies. The literature review is conducted by searching for articles presenting the results of prior research through online platforms or by searching for books online and in libraries.

### 2.5 Data analysis

Data analysis in this research employs both qualitative and quantitative methods. Qualitative data undergoes analysis through the interactive approach, as Miles and Huberman [77] outlined. This includes data reduction, data display, and conclusion drawing. On the other hand, quantitative data undergoes analysis through descriptive statistical analysis, one paired sample t-test analysis, and N-Gain analysis. Descriptive statistical analysis is applied to examine the average learning outcomes of students in both study groups during the pretest and posttest stages. Subsequently, a one-paired sample t-test analysis is utilized to assess whether there is a significant improvement in students' learning outcomes from the pretest to the posttest stages in both study groups. N-Gain analysis is employed to evaluate the level of improvement in students' learning outcomes during the same stages in both study groups [78]. The quantitative data analysis is conducted using the IBM SPSS computer program. IBM SPSS was used because it is one of the most widely used statistical tools in research, especially in social, business, and educational studies [79-81]. IBM SPSS is also well-suited for educational research, such as for correlation and comparison studies [82].

## 3. RESEARCH RESULTS

### 3.1 Model development design

The environmental problem-solving learning model was systematically developed, commencing with preliminary studies and literature reviews of prior research and theories. The model's development was guided by various educational and learning theories, as well as recent research findings, to support meaningful learning objectives and accommodate contemporary advancements. Environmental problem-solving learning represents a fusion of problem-based learning and environmental-based learning. In essence, this approach directs problem-solving in learning toward addressing real-world environmental challenges faced by students. In this research, environmental problem-solving learning is additionally focused on problem-solving utilizing a spatial thinking approach and regional complexity, distinctive features of geographical knowledge. This emphasis is crucial because environmental issues require ecological approaches and spatial and regional complexity approaches to yield comprehensive solutions.

The development of the environmental problem-solving learning model is anchored in the constructivism learning theory, drawing from the works of Piaget, Bruner, Glasersfeld, and Vygotsky. This foundational theory serves as a basis, but the model's development also integrates other pertinent learning theories. These include behaviorism theories proposed by Thorndike, Skinner, Pavlov, and Bandura, cognitive theory from Piaget, Bandura, and Bruner, and humanistic learning theories articulated by Abraham Maslow, Carl Rogers, and Arthur Combs. Furthermore, the environmental problem-solving learning model is crafted concerning learning theories from Gagne and Richard R. Mayer, the social learning theory from Bandura, bloom's taxonomy theory from Anderson and Krathwol [76], and the cone of experience theory from Edgar Dale.

The environmental problem-solving learning model also draws inspiration from various established learning models commonly employed in the teaching and learning process across different educational levels. One of the referenced learning models is cooperative learning and collaborative learning, both group-based learning models. Additionally, the environmental problem-solving learning model incorporates principles of contextual learning, emphasizing the connection between learning materials and the real-world contexts of students.

True to its name, the environmental problem-solving learning model incorporates principles and characteristics of environmental-based learning, specifically eco-pedagogy. Ecopedagogy entails a learning system encompassing teaching related to social and natural environments, teaching in social and natural environments, teaching through social and natural environments, and teaching about the interconnectedness between sustainable beings. The principles of eco-pedagogy include (1) comprehensive learning that develops aspects of knowledge, attitudes, and skills, (2) contextual learning, and (3) emphasis on student engagement and activity in solving problems cooperatively and collaboratively.

Based on the description above, several characteristics of environmental problem-solving learning include: (1) learning directed towards developing students' problem-solving skills and critical thinking, (2) student-centered learning emphasizing student activity to foster student independence, (3) teachers act as facilitators, motivators, and reflectors, (4) collaborative group-based learning to develop cooperation and communication skills, (5) contextual learning using environmental problems and issues surrounding students, (6) comprehensive learning by developing knowledge, skills, and environmental love attitudes in students, (7) learning using technology approaches, including multimedia technology, interactive computer-based technology, and geospatial-based technology, (8) problem-solving learning emphasizing ecological, spatial, and regional complexity approaches, (9) authentic learning assessment, and (10) learning starts from actual environmental problems as stimuli for students to develop and construct their knowledge.

In line with the above characteristics, the researcher constructs the syntax of the environmental problem-solving learning model, which consists of seven main stages. The syntax of environmental problem-solving learning can be seen in Table 1.

The syntax of the environmental problem-solving learning model is universal. This means that this learning model can be applied to a single subject matter and across various topics in geography education. The model is not limited to environmental conservation topics but can be applied to all subjects because every geography lesson in schools can be directed and constructed with an environmental and problem-based approach. This aligns with the characteristics of geography as a science of environmental sustainability, where its primary focus is on the interaction between humans and their environment.

### 3.2 Effectiveness test of environmental problem-solving learning model

In this research, the effectiveness of the environmental problem-solving learning model is assessed by comparing students' learning outcomes between the pretest and posttest stages. The pretest and posttest questions are structured in a multiple-choice format, each comprising 25 items. The trial of the environmental problem-solving learning model is conducted in two distinct classes situated in different areas-urban and rural. The urban study group in this research is from SMA Negeri 3 Semarang in the city of Semarang, while the rural study group is from SMA Negeri 1 Beringin in Semarang Regency.

The learning activities implemented in both urban and rural schools adhere to the characteristics of the environmental problem-solving learning model syntax. Both study groups receive the same learning materials and objectives, specifically focusing on remote sensing using multitemporal satellite imagery on Google Earth Engine. The primary distinction between learning in the two schools lies in the case studies that are tailored to the environmental issues prevalent in the students' respective residential areas.

The environmental problem-solving teaching model in this study used the Google Earth Engine platform as a learning medium to support the effective implementation of the model. Google Earth Engine is a platform provided by Google that can be used for free for mapping purposes and as an educational tool. In geography education, satellite imagery is helpful as a learning medium because it can realistically visualize the earth's surface.

During the experiment or treatment phase, Google Earth Engine was utilized as a learning medium because it can display satellite imagery, allowing students to observe the earth's surface conditions without visiting or directly interacting with the observed objects. Google Earth Engine featu res multi-temporal or timelapse satellite imagery that can show the Earth's surface conditions over time. This feature is particularly beneficial for students to easily and quickly understand the dynamics of surface conditions in the observed area, including the most notable aspect of how land use changes over time.

During the use of Google Earth Engine, students are tasked with observing and analyzing land use changes in their residential areas, utilizing multitemporal satellite imagery from Google Earth Engine. Subsequently, they are required to identify the problems resulting from these land use changes in greater detail. Finally, students analyze and propose optimal solutions to address the environmental issues.

**Table 1.** Syntax of GIS-based environmental problem-solving learning model

| No. | Syntax | Learning Activities |
|---|---|---|
| 1 | Orientation and Apperception | 1. Lesson opening.<br>2. Presentation of topics and learning objectives.<br>3. Apperception activities using videos, maps, images, satellite imagery, or other interactive digital media.<br>4. Question and answer session with students regarding an environmental issue in their surroundings or school.<br>5. Presentation of activities and tasks to be carried out by students.<br>6. Elaboration of the learning process. |
| 2 | Group Building and Environmental Problem Statement | 1. Division of students into small groups (4-6 students per group).<br>2. Presentation of environmental problems to students using interactive media (videos, maps, satellite imagery, etc.). |
| 3 | Environmental Problem Identification | 1. In-depth environmental problem identification process by each group.<br>2. Environmental problem identification is conducted by collecting data and observations using geospatial technology, real environmental surroundings, videos, articles, and other sources. |
| 4 | Environmental Problem-Solving Process | 1. Further data collection to solve environmental problems, including spatial and non-spatial data.<br>2. Students' group discussions and critical reasoning to find solutions to existing environmental problems.<br>3. Formulation of environmental problem-solving results or proposed solutions. |
| 5 | Results Presentation | 1. Each group presents the results of discussions by outlining environmental problems and proposed solutions.<br>2. Other groups provide feedback such as criticism, suggestions, input, elaboration, refutation, and enrichment of the ideas presented by the presenting group. |
| 6 | Concepts Construction | 1. The teacher guides students in constructing concepts and knowledge about the material based on the learning process that has been conducted.<br>2. Students convey the ideas and concepts they have obtained from the learning activities that have taken place.<br>3. The teacher provides reinforcement, enrichment, and refutation of the ideas presented by students to construct concepts, making them more comprehensive. |
| 7 | Evaluation and Reflection | 1. Reflection to identify students' strengths and weaknesses and provide meaningful feedback to students.<br>2. The teacher guides students in deciding the learning activities that have taken place.<br>3. Presentation of activities in the next meeting. |

### 3.3 Pretest results

Based on data analysis, it is observed that the student's learning outcomes in the pretest stage between students in urban areas schools and students in rural areas schools show slight differences, but both groups demonstrate average learning outcomes that are still below the Minimum Mastery Criteria (KKM), which is below 70. The average score of students' learning outcomes in urban areas schools in the pretest stage is 57.58. Meanwhile, the average score of students' learning outcomes in rural areas schools in the pretest stage is 44.23. The analysis of pretest data can be seen in Table 2.

The table above also indicates that in the pretest stage, the minimum score obtained by students from urban and rural area schools is the same, which is 28. However, the maximum scores obtained by students from the two schools show different figures, with the maximum score obtained by students from urban areas schools in the pretest stage being 88. Meanwhile, the maximum score obtained by students from rural areas schools in the pretest stage is 60.

**Table 2.** Students' learning outcomes in the pretest stage

| School | N | Min | Max | Mean | Std. Deviation |
|---|---|---|---|---|---|
| Urban Areas School | 33 | 28 | 88 | 57.58 | 14.385 |
| Rural Areas School | 35 | 28 | 60 | 44.23 | 8.835 |

Source: Analysis results (2023)

The data analysis also shows that in the pretest stage, most students, both in urban and rural areas, are still below the minimum mastery criteria (below 70%). Out of 33 students in urban areas schools, 29 students (87.9%) obtained scores below the minimum mastery criteria, and only four students (12.1%) obtained scores above the minimum mastery criteria. Meanwhile, in rural areas schools, out of 35 students, all of them obtained scores below the minimum mastery criteria. Data on students' minimum mastery in the pretest stage can be seen in Figure 1.

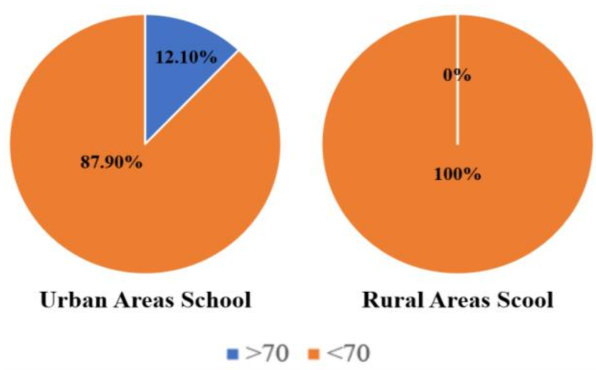


**Figure 1.** Student mastery in the pretest stage

### 3.4 Posttest results

Descriptive data analysis indicates that students' learning outcomes in the posttest stage between students from urban areas schools and rural areas schools are nearly the same. The average learning outcome of students from urban areas schools in the posttest stage is 83.39. Meanwhile, the average learning outcome of students from rural areas schools in the posttest stage is 80.11. A descriptive analysis of students' learning outcomes in the posttest stage is displayed in Table 3.

**Table 3.** Descriptive analysis of students' learning outcomes in the posttest stage

| School | N | Min | Max | Mean | Std. Deviation |
|---|---|---|---|---|---|
| Urban Areas School | 33 | 64 | 100 | 83.39 | 10.683 |
| Rural Areas School | 35 | 68 | 96 | 80.11 | 7.851 |

Source: Data analysis results (2023)

The descriptive analysis in the table above indicates that the minimum score obtained by students from urban areas schools in the posttest stage is 64. Meanwhile, the maximum score obtained is 100. Then, the minimum score obtained by students from rural areas schools is 68. Meanwhile, the maximum score obtained is 96. These results also show that the average learning outcomes of students in the posttest stage are already above the minimum mastery criteria. However, not all students can achieve learning outcomes above the minimum mastery criteria, both in urban areas schools and rural areas schools. Data on students' minimum mastery in the posttest stage can be seen in Figure 2.

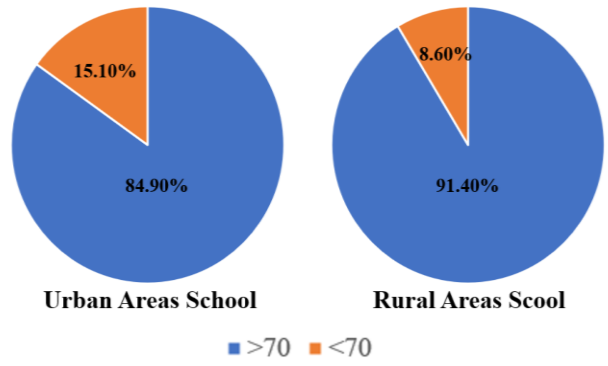


**Figure 2.** Student mastery in the posttest stage

Figure 1 shows that most students in the two research locations have already achieved scores above the minimum mastery criteria. Out of 33 students from urban areas schools, 28 students (84.9%) have obtained scores above the minimum mastery criteria. Meanwhile, the remaining five students (15.1%) have scores below the minimum mastery criteria. On the other hand, out of 35 students from rural schools, 32 students (91.4%) obtained scores above the minimum mastery criteria. Then, the remaining three students (8.6%) have scores below the minimum mastery criteria.

Based on the descriptive data analysis results, there is an improvement in students' learning outcomes from the pretest stage to the posttest stage. However, further analysis is needed to assess the effectiveness of the environmental problem-solving learning model. The one-paired sample t-test is conducted to analyze the effectiveness of the learning model. Before conducting the one paired sample t-test, the normality of the student learning outcome data is tested to verify that the data is usually distributed. In this research, the normality test of student learning outcome data is conducted using the Shapiro-Wilk test method. The data is normally distributed if the p-value is more significant than 0.05. The results of the normality test of the research data are displayed in Table 4.

**Table 4.** Results of normality test of research data

| School | Score | df | p-values | Conclusion |
|---|---|---|---|---|
| Urban Areas School | Pretest | 33 | 0.760 | Normally Distributed |
| | Posttest | 33 | 0.083 | Normally Distributed |
| Urban Areas School | Pretest | 35 | 0.128 | Normally Distributed |
| | Posttest | 35 | 0.078 | Normally Distributed |

Source: Data analysis results (2023)

Based on the table above, it can be observed that all data are typically distributed. The student learning outcome data from urban areas schools in the pretest stage obtained a p-value of 0.760 (>0.05), and in the posttest stage, it obtained a p-value of 0.083 (>0.05), indicating that both are typically distributed. Furthermore, the student learning outcome data from rural areas schools in the pretest stage obtained a p-value of 0.128 (>0.05), while in the posttest stage, it obtained a p-value of 0.078 (>0.05), also indicating normal distribution. After confirming that the data are normally distributed, the analysis proceeds with the one paired sample t-test. The results of the one paired sample t-test analysis can be seen in Table 5.

The table indicates that there is a significant difference between students' learning outcomes in the pretest stage and their learning outcomes in the posttest stage, both in urban and rural schools. Based on the table, it can be observed that the p-value for students from urban areas schools is 0.000 (<0.05), indicating a difference between students' learning outcomes in the pretest and posttest stages. Furthermore, the table also shows that the p-value for students from rural areas schools is 0.000 (<0.05), proving a significant difference between students' learning outcomes in the pretest and posttest stages. The results of the one paired sample t-test analysis demonstrated that the environmental problem-solving learning model is efficacious in improving student's learning outcomes, both in urban and rural schools.

**Table 5.** Results of one paired sample t-test

| School | N | t | p-value | Conclusion |
|---|---|---|---|---|
| Urban Areas School | 33 | 11.052 | 0.000 | Effective |
| Rural Areas School | 35 | 20.542 | 0.000 | Effective |

Source: Data analysis results (2023)

The positive N-Gain scores further show the effectiveness of using the environmental problem-solving learning model. The N-Gain analysis results for students in urban schools' pretest and posttest scores are 0.61, while the N-Gain scores for the pretest and posttest scores of students in rural schools are 0.64. The N-Gain scores obtained by students in both research location schools indicate that the level of effectiveness of the environmental problem-solving learning model falls within the moderate to high category. The analysis results of N-Gain for pretest and posttest scores of students can be seen in Table 6.

**Table 6.** Results of N-Gain analysis

| School | Average of Pretest | Average of Posttest | N-Gain | Category |
|---|---|---|---|---|
| Urban Areas School | 57.58 | 83.39 | 0.61 | Moderate to High |
| Rural Areas School | 44.23 | 80.11 | 0.64 | Moderate to High |

Source: Data analysis results (2023)

## 4. DISCUSSION

The results of this study indicate that the environmental problem-solving learning model, coupled with GIS-based learning media, effectively enhances student learning outcomes. The research findings reveal a significant improvement in student learning outcomes from the pretest to the posttest stage, evident in both urban and rural schools. These outcomes align with several prior studies that have demonstrated the effectiveness of problem-based learning models in elevating student learning outcomes [70, 83-89]. Other studies, such as those by Li and Tsai [90] and Loyens et al. [91], have also demonstrated that problem-based learning models effectively enhance long-term knowledge and conceptual understanding in students.

The effectiveness of the environmental problem-solving learning model is underpinned by the characteristics of the PBL model, which actively encourages students' critical thinking and problem-solving skills, thereby fostering HOTS. The PBL model necessitates active learning on the part of students, enabling them to address problems created by their teachers or reinforced by students themselves. This proactive engagement significantly contributes to students' achievements and effective learning outcomes [92]. Bandura [93] further adds that individuals can progress if they persist in facing difficulties, emerging more potent due to their efforts in challenging situations.

The effectiveness of the environmental problem-solving learning model is further substantiated by carefully selecting environmental issues, which are integrated into contextual learning processes based on students' real-world experiences or issues they can readily identify and experience. This aligns with Tok's assertion [94] that the PBL model aims to facilitate student learning through collaborative group work focused on addressing real-life problems. Consequently, this interactive and innovative learning approach is anticipated to yield improvements in student learning outcomes [95].

The incorporation of real-world issues, coupled with the provision of an open and authentic learning environment that encourages independent exploration of information, is sure to motivate students to engage more actively in problem-solving [96, 97]. The familiarity with real-world problem settings experienced by students facilitates access to prior knowledge stored in their memory, thereby stimulating learning [96]. Gunter and Alpat [98] further emphasize that problems related to everyday situations contribute to the permanence of knowledge acquired by students, thereby enhancing their critical reasoning abilities.

Environmental problem-solving learning adopts a collaborative approach that fosters teamwork among students, with a focus on placing students as the central figures in the learning process. Additionally, the model contributes to the improvement of understanding and explanatory skills [99, 100]. Furthermore, Redman [101] underscores that problem-based learning inherently revolves around complex problems that necessitate more than one correct solution. The essence of PBL lies not only in solving problems but in engaging in discussions about how to solve them [102].

The effectiveness of the environmental problem-solving model underscores the appropriateness of integrating problem-based learning with contextual environmental issues in geography education. Numerous previous studies have demonstrated that problem-based learning is effective in enhancing critical environmental awareness and environmental literacy and fostering positive environmental care attitudes among students [103-108]. Kuvac and Koc [109] further state that through the PBL learning stages, students not only receive and memorize theories but also actively function as problem solvers for environmental issues in their surroundings.

The appropriateness of integrating problem-based learning with contextual environmental issues in the environmental problem-solving learning model aligns with the assertions made by Lozano et al. [110] and Tejedor et al. [111] that the PBL model is highly suitable for realizing education for sustainable development goals (ESD). Dochy et al. [112] argue that the PBL model equips students to understand environmental problems comprehensively. Through PBL, students observe and explore data to identify problems and devise solutions, fostering critical thinking and, consequently, forming attitudes toward environmental care [113]. This is because students' attitudes toward environmental care are more likely to increase when they grapple with authentic environmental problems [114].

Incorporating GIS-based learning media and remote sensing in the environmental problem-solving learning model significantly improves learning effectiveness. The utilization of GIS and remote sensing learning media plays a crucial role in enhancing spatial thinking skills in students, subsequently leading to improved problem-solving abilities. Geographic Information System (GIS) holds the potential to support the learning of geographic concepts by enabling the exploration of real-world problems, ultimately fostering the development of spatial thinking skills [115]. GIS offers a variety of tools for mapping spatial data to address questions in geography, supporting geography education by aiding students in developing spatial analysis skills and engaging them in real-world problem-solving [116]. The findings of a study by Kim and Bednarz [117] also affirm that GIS is beneficial in enhancing students' critical spatial thinking, identified as the ability to assess data reliability, employ reasonable spatial reasoning, and evaluate the validity of problem-solving.

The development of spatial thinking skills significantly contributes to the enhancement of problem-solving abilities in students. This is closely tied to the core concept of spatial thinking, encompassing proficiency in spatial concepts, spatial representation, and spatial reasoning [118]. Geospatial thinking, a subtype of spatial thinking, specifically relating to the Earth, landscapes, and the environment, forms the foundation of society's cognition and understanding of the environment and space [119, 120].

Geography education serves as a platform for acquiring knowledge and skills to comprehensively understand the environment through spatial thinking [121]. Spatial thinking skills within geography learning are crucial elements that students must master to solve problems, given their close relationship [122]. This correlation between spatial thinking skills and problem-solving skills has been analyzed by several researchers, including Golledge [123], Golledge et al. [124], Jackson [125], and Uhlenwinkel [126]. Other studies have demonstrated that spatial thinking skills significantly contribute to the mastery of problem-solving skills [127-131]. Therefore, GIS and remote sensing-based media also play a significant role in augmenting the effectiveness of the environmental problem-solving model in this study [132, 133].

Based on the above discussion, enhancing teachers' skills and abilities in implementing innovative geography education is crucial. Teachers are the frontline and key to successful and effective learning. Therefore, improving teachers' skills must be carried out using various effective methods and strategies, both at the pre-service and in-service stages.

At the pre-service stage, universities that train future geography teachers must equip them with strong pedagogical skills so they can design engaging geography lessons. The geography education curriculum should balance theoretical and practical aspects, providing pre-service teachers with ample hands-on experience. For the government and other stakeholders, enhancing pedagogical skills and competencies for in-service teachers is essential. This ensures that in-service teachers stay updated with innovations in geography education, allowing them to keep up with contemporary developments in daily teaching practices.

Key points to consider in improving the skills of both pre-service and in-service teachers include designing student-centered, contextual geography lessons that encourage active student participation. Teachers should be strongly grounded in spatial, ecological, and regional complexity approaches in geography, enabling them to internalize environmental values and knowledge in every geography lesson. Additionally, mastery of digital technology should be emphasized for geography teachers, especially in remote sensing and geographic information systems (GIS), so they can leverage these technologies to enhance learning effectiveness. Teachers should be trained to shift their mindset and practice from "teaching about GIS" to "teaching with GIS".

## 5. CONCLUSION

The environmental problem-solving learning model with GIS-based instructional media effectively enhances students' learning outcomes in geography. This model advocates for active learning centered on students, promotes collaboration and cooperation among students, and situates students as the primary subjects in the learning process. Moreover, it nurtures the development of critical thinking and problem-solving skills in students. The environmental problem-solving learning model is a well-suited approach for improving students' environmental problem-solving skills and environmental awareness. Integrating problem-based learning with addressing environmental issues around students realizes contextual real-world-based learning by leveraging remote sensing and GIS-based media. The instructional media also contribute to students' learning outcomes by fostering spatial thinking and problem-solving skills.

The findings of this study underscore the substantial potential of the environmental problem-solving learning model for implementation in geography education. GIS-based instructional media is highly recommended to enhance spatial abilities and problem-solving skills, empowering students to act and make decisions in a geographical context. We strongly advocate including the environmental problem-solving learning model with GIS-based media in the professional development of geography teachers, both in pre-service and in-service training. This represents a pivotal step towards fostering more critical, adaptive, interactive, contextual, and spatially-based geography education. It is imperative for various stakeholders, including teachers, school leaders, tutors, or teacher mentors in both schools and higher education institutions, to assume crucial roles as agents of change in championing innovative transformations in geography education, including implementing GIS-based environmental problem-solving models across diverse educational settings.

This study has applied the environmental problem-solving learning model in two classes from distinct schools with different backgrounds, encompassing urban and rural areas. Further developments of this study can be conducted on other subjects or study groups. The environmental problem-solving teaching model can be universally applied to geography lessons in various regions, each with its environmental conditions. Subsequent research endeavors aim to implement this environmental problem-solving model across broader subjects and a more diverse array of environmental issues that are relevant to the specific conditions faced by each school subject. Additionally, further research is encouraged to apply this learning model to a broader spectrum of geography learning materials, given its flexibility and universality, making it applicable to various subjects [134]. Various technological innovations in GIS and remote sensing, in addition to Google Earth Engine, can also be applied to further develop the environmental problem-solving teaching model. Moreover, a more profound and realistic analysis of the instructional impact of this model is needed. This analysis should not solely focus on cognitive learning outcomes but should also encompass a comprehensive assessment of students' abilities, including problem-solving, critical thinking, spatial thinking, environmental attitudes, and social attitudes.

## AUTHOR CONTRIBUTIONS

Edi Kurniawan and Mohammad Syifauddin conceived of the presented idea. Mohammad Syifauddin and Muh. Sholeh developed the theory and performed the computations. Edi Kurniawan and Siti Nurindah Sari verified the analytical methods. Edi Kurniawan and Siti Nurindah Sari supervised the findings of this work. All authors discussed the results and contributed to the final manuscript.

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## CONFLICT OF INTEREST

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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