

Development of Transdisciplinary Integration Innovation to Promote Geo-literacy of High School Students

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Abstract: The objectives of this research were threefold: 1) to investigate the historical development, systemic challenges, and structural limitations of the geography curriculum in Thailand; 2) to design and develop a transdisciplinary learning innovation aimed at promoting the geo-literacy of high school students; and 3) to evaluate the pedagogical effects of implementing this transdisciplinary innovation. Employing a sequential mixed-methods research design, the study gathered data from two distinct target groups: a panel of five subject-matter experts who evaluated the structural validity of the innovation, and an experimental group of 150 upper-secondary students who participated in the instructional intervention. The research instruments comprised a qualitative document synthesis protocol, an innovation suitability evaluation form, a comprehensive geo-literacy competency assessment, and a semi-structured focus group discussion matrix. Qualitative data underwent thematic content analysis, while quantitative metrics were analyzed using descriptive statistics ($\bar{x}$ S.D.) and inferential statistics (paired-samples t-test). The findings revealed that: 1) The evolution of the Thai geography curriculum progressed through four historical paradigms, shifting from spatial positivism aimed at territorial unification to a post-humanist framework within the contemporary Basic Education Core Curriculum. A critical systemic limitation identified was the persistent overemphasis on passive rote memorization and disjointed disciplinary silos, which broadens the gap between theoretical geography and real-world environmental phenomena. 2) The development of the Transdisciplinary Learning Innovation—operationalized through the Phenomenon-Based Transdisciplinary Boundary-Crossing (PB-TBC) mechanism and the Contour Model—synthesized geography into five core dimensions: Geo-Knowledge, Geo-Process, Geo-Abilities, Geo-Integration, and Geo-Literacy. Expert validation rated the overall quality of this instructional innovation at the highest qualitative level ($\bar{x}$ =4.60, S.D.=0.67). 3) Empirical implementation demonstrated that the innovation significantly enhanced student competencies, with the post-test geo-literacy scores reaching an outstanding level ($\bar{x}$ =3.82, S.D.=0.40). Furthermore, inferential verification confirmed a statistically significant improvement in students' spatial decision-making and problem-solving capacities ($p<.05$), proving that the innovation successfully transformed passive learners into proactive data creators capable of navigating complex socio-environmental challenges.

Keywords: Geo-literacy, Geography Curriculum, Transdisciplinary Integration, Learning Innovation, Phenomenon-Based Learning.

1. Introduction

In the contemporary era of the Anthropocene, the relentless drive for national macroeconomic growth has accelerated natural resource depletion and disrupted

global ecological balances. Humanity currently faces unprecedented, interconnected socio-environmental crises, characterized by extreme weather events, biodiversity loss, and severe atmospheric degradation. As noted by Castree (2014), understanding these shifts has become the primary mandate of geographical education in the modern era. Educational paradigms must therefore pivot toward equipping next-generation learners with the cognitive tools necessary to decode the complex, non-linear feedback loops between human activities and environmental systems, fostering sustainable spatial strategies for planetary viability.

Geography is uniquely positioned as a critical spatial science capable of elucidating these phenomena by examining the dynamic interactions between biophysical and human systems across varying spatial scales. It serves as an essential core body of knowledge for interpreting, mapping, and assigning meaning to an increasingly fragmented world (Lambert & Morgan, 2010). Regrettably, conventional secondary geography education in many developing nations, including Thailand, remains structurally deficient. Traditional curriculum designs, textbook configurations, and instructional methodologies frequently treat geography as a descriptive repository of static facts rather than an active spatial science. By artificially segregating content into rigid sub-disciplinary silos—such as physical, human, regional, and economic geography—the classroom degenerates into a data warehouse. Consequently, students are conditioned to become mere “rote memorizers” tasked with recalling isolated facts for high-stakes national university entrance examinations, a practice that severely limits the holistic development of both tangible and intangible learning outcomes.

Furthermore, the exponential growth of geospatial technologies and the influx of massive data streams have radically transformed global societal contexts, rendering traditional, static geographical theories obsolete (Khosanan, 2012). To remain relevant, modern geographical education must transition toward student-centered, active learning frameworks that empower learners to autonomously navigate, synthesize, and manage large-scale data environments (Office of the Education Council, 2019; Yan, 2012). Secondary geography must be re-engineered to foster essential 21st-century attributes, including global citizenship, cross-cultural empathy, and digital literacy, enabling students to address complex, multi-criteria spatial problems.

To transcend the structural constraints of traditional disciplinary subdivisions, a radical paradigm shift toward transdisciplinary integration is required. This shift demands that educators evolve from passive instructors into learning experience designers who facilitate self-directed knowledge construction anchored in Constructivism. Developing authentic geo-literacy requires an instructional framework that stimulates intrinsic motivation by linking foundational spatial concepts with the students’ immediate lived experiences through Area-Based and Phenomenon-Based Learning (Office of the Education Council, 2019). By utilizing the local geographic context as a living laboratory, students engage in systematic geographic inquiry to foster future-ready operational skills (e-Estonia, 2018).

True knowledge synthesis occurs when integration allows learners to trace spatial causality across diverse disciplines, mirroring the complexity of real-world challenges (National Academy of Sciences, 2005). Through active learning processes, students confront external societal crises and apply reasoned spatial analysis to

formulate self-generated, innovative solutions (Problem-Solving), thereby evolving into autonomous learners (Ministry of Education, 2017; van Kerkhoff & Lebel, 2006). This pedagogical journey cultivates systems thinking, environmental empathy, and a profound awareness of the learner's civic role in influencing positive spatial changes within their communities (Kerski, 2022; Mangkhang, 2018). Ultimately, geo-literacy empowers students to view geographical landscapes holistically, distinguish structural variables, mitigate socio-environmental vulnerabilities, and assume the responsibilities of transformative, active global citizens (Meadows, 2020).

Consequently, this study addresses this educational imperative by developing and evaluating a Transdisciplinary Learning Innovation. This framework serves as a critical pedagogical mechanism to elevate upper-secondary learning outcomes by harmonizing conceptual understanding, technological operation, and geographic competencies. Strategically designed to harness students' intrinsic motivation, the innovation enables learners to co-produce original "Spatial Innovations" that reflect deep critical self-reflection and civic responsibility, thereby providing a scalable model for modernizing geographical education within the next-generation global context.

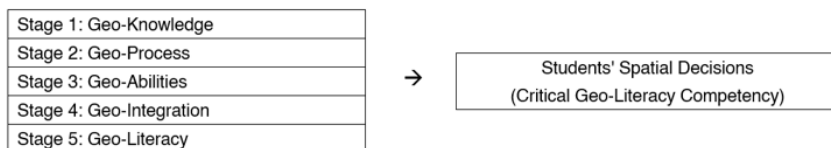
2. Literature Review

Modern geography education faces a critical juncture under the intense socio-environmental disruptions of the Anthropocene (Castree, 2014). High school students tend to have the potential to bear and face complex spatial problems when equipped with systematic inquiry skills, remaining open to the dynamic events and environmental happenings of our world. However, learning traits and human competencies manifest differently under different educational paradigms and curriculum structures. Educational traits which are anchored in transdisciplinary integration—specifically spanning knowledge synthesis, procedural inquiry, technical abilities, cross-boundary integration, and critical geo-literacy—are highly valuable for future citizens (Edelson, 2014). Many scholars have given their conclusion of studies that this vital transdisciplinary integration dimensions can bring a positive change in students' personal, academic, and professional lives.

The focus of the current study is to check the structural impact of these five pedagogical dimensions on the students' spatial decisions. This article highlights the literature on contemporary curriculum constraints and secondary school students' decision to engage in real-world environmental mitigation. In this literature, the five important transdisciplinary dimensions discussed in our study are covered. Extensive research work has been conducted on general curriculum integration, but it is still understudied how a definitive pedagogical mechanism—specifically the "Phenomenon-Based Transdisciplinary Boundary-Crossing (PB-TBC)" mechanism implemented via the "Chiang Mai Metropolis" innovation—influences a high school student's competency to make sustainable spatial decisions through these five sequential dimensions. This study explains each transdisciplinary innovation dimension separately to predict a student's spatial decision choice in secondary education.

Transdisciplinary Innovation Dimensions

Figure 1: Theoretical Framework of the Study Illustrates the Learning Process Designed for Transdisciplinary Integration Innovation to Promote Geo-literacy of High School Students.



2.1. Geo-Knowledge and Students' Spatial Decision

When something is going wrong in the immediate environment, usually traditional education says the first thing is to memorize facts from textbooks for national high-stakes examinations. This applies to conventional classrooms which isolate geography into rigid, fragmented subject silos. Having a strong foundational understanding of Geographic Concepts, Regional Geography, Systematic Geography, and Technical Geography & Geographic Application can be significantly better at the educational workplace. People look at the geography curriculum as an improved and attractive framework when it demonstrates systematic real-world connections through a robust contour of content. A holistic knowledge perspective is important in every educational field, but the more important reason is to stay integrated at the secondary school level where regional crises occur. Transdisciplinary innovation treats foundational geographical knowledge as an essential first component. In a nutshell, a structured knowledge dimension is an emerging trend, and it is important to investigate how conceptual understanding—built upon a progression from raw concepts to technical geographic applications—directly or indirectly influences the selection of sustainable problem-solving in the contemporary education of a student. From the above discussion, it can be assumed as:

H1: The Geo-Knowledge dimension within the transdisciplinary innovation has a significant impact on students' spatial decisions.

2.2. Geo-Process and Students' Spatial Decision

The ability to execute geographic inquiry is deeply linked with active learning procedures, cognitive engagement, and student problem-solving traits. Within the designed learning process, it has been observed that students who engage in formal inquiry steps feel more confident and enjoy high academic self-esteem. Conversely, learners confined to a static process feel that they do not possess the actual inquiry mechanisms to decode real-world spatial problems, treating geography as an abstract and heavy burden. Transitioning to modern geographic inquiry within an active learning process is highly related to handling operational tasks sequentially. By engineering a definitive inquiry process that allows high schoolers to navigate systematically through Geographic Questioning, Geographic Data Collection, Geographic Data Management, Conclusion and Presentation, and Evaluation and Reflection, the framework transforms a theoretical construct into a tangible step-by-step tool. From the discussion, a hypothesis can be formulated as:

H2: The Geo-Process dimension within the transdisciplinary innovation has a significant impact on students' spatial decisions.

2.3. Geo-Abilities and Students' Spatial Decision

Geographical competence and critical spatial decision-making are deeply linked with technical operational tools, data manipulation skills, and spatial visualization (Gallagher & Downs, 2012). It has been observed that students who master technical geoinformatics applications during a course feel more confident and enjoy high learning self-esteem. Several students and teachers are pushed away from developing actual spatial abilities due to structural circumstances in the traditional Thai educational context, i.e., the high cost and official confidentiality restrictions of official topographical maps from the Royal Thai Survey Department, which deprives classrooms of practical experience. To resolve this deficit, our innovation directly cultivates a sequential matrix of Spatial Perception, Geographic Interpretation, Geographic Reasoning, Systematic Decision-Making, and Adaptation and Planning. This targeted cognitive development allows students to utilize open-source GIS tools confidently, transforming high schoolers into spatial operators who can navigate cartographic uncertainty and execute risk-taking spatial planning. From the discussion, a hypothesis can be formulated as:

H3: The Geo-Abilities dimension within the transdisciplinary innovation has a significant impact on students' spatial decisions.

2.4. Geo-Integration and Students' Spatial Decision

Studies suggest that there is classroom pressure, anxiety, and passive learning issues in traditional social studies environments that isolate academic topics. To understand the importance of cross-cutting integration for the selection of sustainable spatial actions, it is important to highlight the disadvantages of a fragmented curriculum mindset as well. A negative, fragmented subject mindset inculcates disjointed thoughts which can lead to a lack of confidence and analytical underperformance among learners. Within the current innovation, this integration is not treated as a static condition but as a progressive technique spanning five distinct levels: Disciplinary, Infusion, Parallel, Interdisciplinary, and Transdisciplinary. By systematically elevating students through these techniques, the framework forces a helix-synthesis of separate fields into a unified analytical lens, allowing high schoolers to address regional crises like the PM 2.5 smog crisis through deep socio-spatial reconfiguration. Literature supports to build a hypothesis given as:

H4: The Geo-Integration dimension within the transdisciplinary innovation has a significant impact on students' spatial decisions.

2.5. Geo-Literacy and Students' Spatial Decision

Social and collaborative academic relations are very important to be satisfied and active in the final stage of the learning environment. In this framework, the geo-literacy dimension represents the ultimate synthesis of advanced spatial reasoning and civic accountability, materialized through four integrated pillars: Spatial Concepts, Spatial

Experience, Geographic Operations, and Geographic Application. Good relations and structured protocol dialogues with non-academic stakeholders—such as community mentors, local farmers, and public health practitioners—give learners the confidence to co-produce socially robust solutions. Navigating the socio-environmental changes of the Anthropocene requires advanced civic competencies, guiding students to utilize their spatial experience and field operations as real-world tools for sustainable spatial decision-making and green citizenship. Literature supports to build a hypothesis given as:

H5: The Geo-Literacy dimension within the transdisciplinary innovation has a significant impact on students' spatial decisions.

3. Research Methodology

This study adopted a sequential mixed-methods research design, recognized for its efficacy in triangulating qualitative and quantitative data to achieve a comprehensive, multi-layered understanding of complex educational phenomena. The methodology unfolded across three integrated phases: qualitative document synthesis to map curricular trajectories; expert qualitative suitability validations; and a quantitative experimental intervention paired with post-structural focus group discussions.

1) Participants and Sampling

The research engaged two distinct target populations:

- 1.1) The Expert Validation Panel: Comprised five highly qualified individuals, including university professors in geoinformatics, senior curriculum specialists, and master schoolteachers in social studies learning management. This panel was selected via purposive sampling to ensure rigorous qualitative oversight regarding the innovation's structural components.
- 1.2) The Experimental Student Cohort: Comprised 150 upper-secondary students enrolled in an advanced special classroom program at a prominent secondary school in Chiang Mai Province, Thailand. This cohort was selected through simple random sampling from an institutional population of 550 geography students to participate in the fieldwork and innovation testing.

2) Research Instruments

Data collection was facilitated through four specifically designed instruments:

- 2.1) Documentary Synthesis Form: Used to systematically extract, categorize, and analyze historical curricular paradigms and systemic educational directives in Thailand.
- 2.2) Innovation Suitability Assessment Scale: A 5-point Likert scale instrument completed by the expert panel to evaluate the academic validity, alignment, and clarity of the transdisciplinary framework.
- 2.3) Geo-Literacy Competency Assessment Matrix: A comprehensive multi-criteria evaluation tool used to measure students' post-intervention spatial knowledge, technical skills, and problem-solving capacities.
- 2.4) Semi-Structured Focus Group Discussion Protocol: Used to capture qualitative reflections, cognitive shifts, and pedagogical insights from both instructors and students during the debriefing phase.

3) Data Collection and Operational Phases

The research operations were executed through a structured three-tiered process: Phase 1: Diagnostic & Documentary Synthesis: A thorough historical investigation of Thai geography curricula was conducted to identify recurring structural bottlenecks, fragmentation points, and time-allocation deficits in secondary social studies education.

Phase 2: Architectural Design & Quality Assurance: The Transdisciplinary Learning Innovation was mapped and constructed. The resulting instructional packages, digital geoinformatics protocols, and fieldwork manuals were submitted to the five-member expert panel for blind quality evaluation and consensus validation.

Phase 3: Pedagogical Intervention & Evaluation (Lessons Learned): The validated innovation was deployed in the field with the 150 experimental participants. Students engaged in active, phenomenon-based spatial inquiry projects. Following the intervention, the geo-literacy assessment was administered, and focus group discussions were conducted to crystalize the experiential data.

4) Data Analysis

To evaluate the pedagogical progression and verify the structural impact of the transdisciplinary learning innovation, descriptive statistics—including arithmetic mean ($\bar{D}$) and standard deviation (S.D.)—were computed for each geo-literacy component. Furthermore, to determine whether the competency growth between the initial developmental cycle (Units 1–2) and the advanced transdisciplinary cycle (Units 3–4) was statistically significant, a paired-samples t-test was executed. The inferential statistical formula for the dependent t-test is expressed as follows:

$$t = \frac{\sum D}{\sqrt{\frac{n \sum D^2 - (\sum D)^2}{n-1}}}$$

Where:

t = The computed t-test value for dependent samples

D = The difference between the paired scores of each individual participant (Advanced Score–Initial Score)

$\sum D$ = The sum of all individual differences

$\sum D^2$ = The sum of the squared individual differences

N = The total number of participants in the experimental cohort ($N=150$)

df = The degrees of freedom, determined by $n-1$ ($df=149$)

The statistical significance threshold for all inferential analyses was strictly established at $\alpha=0.05$

4. Research Results

3.1. Historical Evolution and Systemic Limitations of the Thai Geography Curriculum

The qualitative synthesis of Thailand's geographical education trajectory revealed that the curriculum has evolved through four distinct historical paradigms, reflecting shifting state ideologies and epistemological trends:

- (1) The National Study Project Curriculum Phase (1898–1936): Driven by the imperative of national administrative unification during the threat of Western colonialism, geography was integrated into the formal social studies apparatus. Grounded in rigid Positivism, the instructional focus was strictly descriptive, emphasizing the physical mapping of regional boundaries, topographic features, and administrative divisions (Mondhon) to validate state territorial integrity (Ministry of Education, 1925).
- (2) The Upper Secondary Certificate Curriculum Phase (1960–1977): As Thailand sought international modernization, the curriculum expanded to a global regional scope, mandate-mapping the six inhabited continents. This phase blended Positivism with early Structuralism, institutionalizing basic cartographic drawing and map-reading skills under a centralized social studies framework to streamline national evaluation metrics (Ministry of Education, 1977; Pongprayoon, 2007).
- (3) The Upper Secondary Curriculum Phase (1981–1990): Designed to support rapid industrialization and macroeconomic export policies, the curriculum repositioned physical geography, population education, and resource conservation as compulsory components. Concurrently, elective tracks adopted a Humanistic Paradigm, introducing systematic human geography courses to explain the dialectical relationship between human cultural practices and physical environments (Ministry of Education, 1992).
- (4) The Basic Education Core Curriculum Phase (2001–2017): This contemporary framework operates under a Post-Humanist lens, broad-blending social sciences to establish two core geographic standards: understanding physical earth systems through spatial tools, and evaluating human-environment interactions to promote sustainable development. The 2017 revision introduced specialized geographic processes and technical skills to foster modern spatial reasoning (Ministry of Education, 2017) (Table 1).

3.2. Systemic Limitations Identified in Conventional Models

Despite these revisions, the analysis exposed three severe structural bottlenecks that impede the development of authentic geo-literacy:

- 1) The Rote-Memorization Trap: Classroom delivery remains heavily constrained by a traditional knowledge paradigm that confines geography to isolated disciplinary silos. Instruction focuses on memorizing fragmented facts to pass national multiple-choice examinations, depriving students of the capacity to value, appreciate, or decode their immediate environmental realities (Phenomenon-Based constraints).
- 2) The Disconnect from Real-World Phenomena: Although geography textbooks explicitly address macro-level crises like global warming, they fail to bridge these concepts with local contexts. Consequently, students demonstrate an awareness of global environmental problems but fail to translate this knowledge into localized behavioral adaptation, green citizenship, or environmental activism.
- 3) Technical Constraints and Competency Deficits: Secondary schools suffer from severe time-allocation deficits and an inflation of factual content. Crucially, while the national curriculum mandates advanced cartographic and geoinformatics literacy, actual classroom access to official topographical maps is severely restricted due to high acquisition costs and government confidentiality regulations. This structural barrier deprives students of hands-on spatial tracking experience.

Table 1: Summary of the Development of the High School Geography Curriculum in Thailand.

Phase	Curriculum (A.D.)	Geographic Knowledge							Geographic Paradigm	
		Geography Concepts	Systematic Geography			Technical Geography		Regional Geography		
		Spatial Concepts	Physical	Human	Environment and Society	Geographic Tools		Local Regions		International Regions
						Maps	Tools			
1	1898					C		C		Positivism
	1936					C		C		
2	1960		E	E		C&E			C	Positivism & Structuralism
	1975		E			E			C	
	1977		E	E	E	E		C	C	
3	1981		C	C&E	C	C&E		C		Humanism
	1990		C	E	C	E		C		
4	2001		C	C	C	C	C	C	C	
	2008		C	C	C	C	C	C	C	
	2017		C	C	C	C	C	C	C	Post-Humanism
* C=Core Subject. E=Elective Subject. C&E= Core& Elective Subject										

* C=Core Subject, E=Elective Subject, C&E= Core& Elective Subject

3.3. Development of the Transdisciplinary Learning Innovation

These phases are: 1) Studying the conceptual components and knowledge base of geography; 2) Synthesizing geo-literacy; and 3) Developing the transdisciplinary integration innovation to promote geo-literacy among high school students. The specific details are as follows:

Table 2: Core Conceptual Elements and Knowledge Components of Geography at the Upper Secondary Education Level.

Major Branch	Content Area	Key Knowledge Domain
Geographic Concepts	Spatial Concepts	Key Knowledge Domain
		Location
		Area/Space
		Place
Systematic Geography	Physical Geography	Physical Systems
	Human Geography	Human Systems
	Environment and Society	Human-Environment Interaction
		Management and Sustainable Development
Geographic Techniques and Application	Geographic Tools	Maps and Mental Mapping/Cognitive Maps
		Geographic Information Systems (GIS) and Geographic Technology
	Application of Geography	Application of Geographic Knowledge and Skills
		Utilization of Knowledge from Geographic Study
Regional Geography	Spatial Experience/Regional Experience	

(1) Studying the conceptual components and knowledge base of geography.

The definition of spatial meaning gives rise to fundamental knowledge across various disciplines, including Geography, Architecture, Fine Arts, and Economics. Related and interconnected concepts broadly explain spatial phenomena and interactions. Key fundamental concepts in geography revolve around Location, Space, Place, and the Earth system & Environment (Lambert & Morgan, 2010). Concurrently, the classification of geographical branches varies in scope and study focus according

to specific objectives. This is evident from a synthesis of geographical concepts and knowledge derived from Haggett (2001), the National Geography Olympiad (The Promotion of Academic Olympiad and Development of Science Education Foundation, 2014), National Geography Standards (Gallagher & Downs, 2012), the United Kingdom's national curriculum (Rawling, 2022), and Thai high school geography textbooks (Aksorn Charoen Tat, 2017), as presented in Table 2.

(2) Synthesizing geo-literacy.

A conceptual framework is employed to understand the interaction between space and personal experience, acknowledging its diverse and non-deterministic dimensions, which are conditioned by the interplay of knowledge, relationships, and shared spatial experiences (Lambert & Morgan, 2010). This framework is constructed by synthesizing key components from the 2017 Thai curriculum, as well as the United States Geography Standards and the UK Geographical Association's curriculum concept for schools. The synthesis emphasizes the core elements of skills, processes, and abilities necessary for making informed, reasoned decisions in daily life, while considering spatial and practical contexts. This approach ultimately facilitates daily planning and strategy development aimed at reducing environmental costs and fostering active citizenship (Gallagher & Downs, 2012; Ministry of Education, 2017; Rawling, 2022). The results of this synthesis are presented in Table 3.

Table 3: Geo-literacy Components at the High School Level.

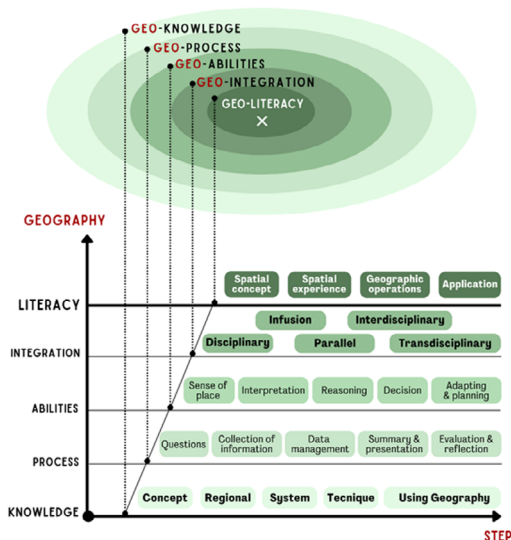
Geographic Processes	Geographic Skills	Geographic Capabilities
(1) Geographic Questioning	(1.1) Spatial Observation	(1) Developing Geographic Perspectives <i>Outcome: Creating spatial relationships</i>
	(1.2) Spatial Thinking	
(2) Geographic Data Collection	(2.1) Spatial Inquiry	(2) Geographic Interpretation <i>Outcome: Spatial perception/awareness</i>
	(2.2) Fieldwork Operations	
(3) Geographic Data Management	(3.1) Use of Data and Basic Statistics	(3) Geographic Reasoning <i>Outcome: Prediction and interconnection</i>
	(3.2) Interpretation and Analysis	
(4) Conclusion and Presentation	(4.1) Problem Solving and Impact Assessment	(4) Systematic Decision-Making <i>Outcome: Generation of new concepts</i>
	(4.2) Dissemination of Processes and Findings	
(5) Evaluation and Reflection	(5.1) Interpreting Geographic Reasoning	(5) Geographic Application <i>Outcome: Adaptation and planning</i>
	(5.2) Spatial Reflection	

The component of geo-literacy (Geographic Literacy) thus constitutes a powerful core framework in fostering learners' profound and systematic understanding of geographical concepts. This is not merely limited to the recognition of spatial data, but critically encompasses the integration of skills, processes, and abilities tailored to the developmental stages of each learner. The ultimate goal is to enable learners to analyze and interpret geographical phenomena with significant insight. This driving force focuses on cultivating a deep awareness and comprehension of the complex human-environment interaction and the intricate relationships between diverse cultures and distinct populations within the contemporary global context. The implementation necessitates the capability to manage and transform Big Data into actionable Geographic Information through the application of advanced Spatial Analysis tools and techniques. Subsequently, a comprehensive process of processing and synthesis is required to yield optimal solutions or effective approaches to pressing geographical and societal issues. This aligns with the overarching educational objective of cultivating adaptable and globally informed citizens capable of navigating change intelligently.

(3) Developing the transdisciplinary integration innovation to promote geo-literacy among high school students, revealed Based on the principles of transdisciplinary integration innovation, a five-level learning framework has been designed to promote geo-literacy among high school students, encompassing: 1) Knowledge, 2) Process, 3) Abilities, 4) Integration, and 5) Geo-literacy. At each level, the educator must identify the problem and the constraints of the existing geography content and curriculum to analyze the utility of the existing lessons. Subsequently, instructors collectively establish objectives that align with real-world environmental contexts and student developmental levels to foster creativity and appropriate problem-solving skills based on life experiences. This approach prepares students for system knowledge, providing comprehensive insights necessary for further knowledge integration. The framework emphasizes the integration of geographical knowledge to synthesize theories from two or more disciplines, resulting in deeper, more authentic, real-life-like learning. This flexible and diverse knowledge integration process prioritizes the beneficiaries of the developmental process, ensuring the learning acts as a cohesive unit where each subject interlinks and interacts with others. The integration is structured into five levels to enhance the shared understanding of the operational models, methodologies, goals, and learning outcomes, ultimately leading to the acquisition of target knowledge, as illustrated.

Figure 2 The Integrated Knowledge Contour Model for Promoting Geo-Literacy aimed at developing the geo-literacy of high school students. This innovation serves to measure students' geo-literacy against their individual potential and the pre-determined instructional goals outlined in the curriculum plan. The outcome of this knowledge integration process fosters competency in students, enabling them to engage in critical discourse and critique knowledge effectively. This, in turn, promotes lifelong learning by cultivating several key competencies: making science accessible, making thinking visible, orchestrating social supports for collaborative learning, and promoting autonomy. Ultimately, this approach leads to the realization of learning innovations of the future.

Figure 2: The Integrated Knowledge Contour Model for Promoting Geo-Literacy.



The study reveals that the application of the transdisciplinary learning innovation model to promote geo-literacy consists of 4 learning plans. These plans utilize learning activities categorized by geo-literacy levels and are evaluated through a geo-literacy assessment, divided into 2 phases as follows:

- 1) Initial Phase: Unit 1, Philosophical Principles of Geography: Activity: “Sense of Place” to build spatial experience, Focus: Foundational knowledge of geographic concepts, Process & Ability: Uses geographic questioning to develop spatial perception, Integration: Employs primary techniques-Disciplinary & Infusion, and Outcome: Focuses on developing spatial concepts. And Unit 2, Physical Geography: Activity: “Toponym Podcast” to understand physical spatial contexts, Focus: Physical geography content, Process & Ability: Uses data collection and management to develop systematic decision-making, Integration: Employs intermediate techniques- Parallel & Interdisciplinary, Outcome: Focuses on developing spatial experience. And Assessment: Aligned with learning activities and geo-literacy levels, evaluating concepts and experiences through abstract spatial activities (Sense of Place) and communication abilities (Toponym Podcast).
- 2) Advanced Phase: Unit 3, Human Geography: Activity: “Ecological Footprint” to promote spatial knowledge integration, Focus: Human geography content, Process & Ability: Uses conclusion and presentation processes to develop spatial perception. And Unit 4, Technical Geography & Geographic Application: Activity: “Chiang Mai Metropolis” to promote geo-literacy through hands-on practice and spatial problem-solving, Focus: Holistic application of geographic knowledge, Process & Ability: Uses evaluation and reflection processes to develop adaptation and planning abilities, Integration: Employs advanced techniques- Transdisciplinary, and Outcome: Focuses on geographic application, measured by the Geo-Literacy Assessment Form for High School Students (Table 4).

Table 4: Geo-Literacy Levels for High School Students.

Unit	Learning Plan	Learning Activity	Geo-Literacy Levels				
			Knowledge	Process	Abilities	Integration	Geo-literacy
1	Philosophical Principles of Geography	Sense of Place	Geographic Concepts	Geographic Questioning	Spatial Perception	Disciplinary & Infusion	Spatial Concepts
2	Physical Geography	Toponym Podcast	Systematic Geography	Data Collection & Management	Interpretation & Reasoning	Parallel & Interdisciplinary	Spatial Experience
3	Human Geography	Ecological Footprint		Conclusion & Presentation	Systematic Decision-Making	Transdisciplinary	Geographic Operations
4	Technical Geography & Geographic Application	Chiangmai Metropolis	Geographic Application	Evaluation & Reflection	Adaptation & Planning		Geographic Application

The researcher subsequently submitted the transdisciplinary integration innovation—which was designed to enhance the geo-literacy of high school students—for quality evaluation by a panel of subject-matter experts. The resulting feedback and evaluation outcomes were as follows:

The data in Table 5 indicate an exceptionally high level of consensus among the experts ($\bar{X}$ =4.60, S.D.=0.67). The panel gave the highest ratings to the academic accuracy of the content, the seamless integration of open-source GIS tools, the

logical sequence of the learning steps, and the calibration of cognitive challenges, confirming that the innovation is highly optimized for classroom implementation.

Table 5: presents the Mean, Standard Deviation, and Interpretation of the Evaluation Results Pertaining to a Transdisciplinary Integration Innovation Aimed at Developing Geo-literacy among High School Students. This Evaluation of Quality was Conducted by a Panel of Five Experts (N=5).

Evaluation Item		SD	Interpretation
1.The content of the innovation is academically accurate and current with contemporary global situations.	4.80	0.45	Highest
2.The innovation enables me to concretely link geographical knowledge with other disciplines (e.g., Science, Social Studies).	4.60	0.55	Highest
3.The activities within the innovation are diverse and stimulate my geographical analytical thinking.	4.40	0.89	High
4.The media/tools utilized in the innovation (e.g., digital maps, GIS) are appropriate and user-friendly.	4.80	0.45	Highest
5.The innovation promotes my practice in problem-solving skills and decision-making supported by spatial data.	4.60	0.89	Highest
6.The sequence of learning steps in the innovation is clear and easy to follow.	4.80	0.45	Highest
7.The innovation increases my interest and awareness of geographical problems and phenomena occurring around me.	4.20	1.10	High
8.The innovation presents an appropriate level of challenge relative to the abilities of secondary school students.	4.80	0.45	Highest
9.The innovation promotes learner-centered learning and provides opportunities for me to express my opinions.	4.60	0.89	Highest
10.Overall, this set of interdisciplinary learning innovation possesses high quality and warrants continued use in instruction.	4.40	0.55	High
Overview	4.60	0.67	Highest

3) Pedagogical Effects of the Transdisciplinary Learning Innovation

Following the field deployment of the innovation with the experimental cohort (n=150), a comprehensive geo-literacy competency assessment was administered. The empirical findings are detailed in Table 6, revealed the researchers implemented a pedagogical process structured around the steps of transdisciplinary integration innovation to promote the geo-literacy of high school students. To evaluate the geo-literacy outcomes achieved through the implementation of the learning plans and the geo-literacy manual, the researcher utilized a specialized geo-literacy assessment form. Data were analyzed using statistical software to determine the Mean () and Standard Deviation (S.D.). The results were interpreted based on a 4-level scale as follows:

- 3.01–4.00: Exceeding Expectations (Identity Perception)
- 2.01–3.00: Proficient (Perspective Understanding)
- 1.01–2.00: Developing (Discovery of Special Characteristics)
- 0.00–1.00: Beginning (Experience Discovery)

Table 6, the inferential statistical analysis utilized a paired-samples t-test to assess the progression of student competencies between the initial integration phase (Units 1–2) and the advanced transdisciplinary cycle (Units 3–4). As illustrated in Table 6, the composite geo-literacy score exhibited a statistically significant increase, moving from an initial mean of 3.77 (S.D.=0.41) to an advanced mean of 3.82 (S.D.=0.40), yielding a highly significant t-value ($t(149) = -5.240, p < .001$). When broken down by individual

structural dimensions, Spatial Concepts demonstrated the most pronounced linear growth, rising from 3.77 to 3.84 ($t(149) = -3.112, p=.002$). This significant increase indicates that as students transitioned to advanced units, their structural understanding of geographic concepts—specifically location tracking and biophysical earth systems analysis—became highly consolidated. Furthermore, significant statistical variances were also confirmed across both Spatial Processes ($t(149) = -2.154, p=.033$) and Spatial Abilities ($t(149) = -2.065, p=.041$).

Table 6: Paired-Samples t-test Comparing Student Geo-Literacy Competency Performance Between Initial and Advanced Phase (N=150).

Geo-Literacy Component	Learning Cycle		S.D.	Mean Diff.	t	p	Performance Level
1. Spatial Concepts	Initial Cycle (Unit 1-2)	3.77	0.41	-0.07	-3.112	.002	Exceeding Expectations
	Advanced Cycle (Unit 3-4)	3.84	0.39				Exceeding Expectations
2. Spatial Processes	Initial Cycle (Unit 1-2)	3.77	0.43	-0.04	-2.154	.033	Exceeding Expectations
	Advanced Cycle (Unit 3-4)	3.81	0.42				Exceeding Expectations
3. Spatial Abilities	Initial Cycle (Unit 1-2)	3.77	0.38	-0.03	-2.065	.041	Exceeding Expectations
	Advanced Cycle (Unit 3-4)	3.80	0.40				Exceeding Expectations
Composite Overview	Initial Cycle (Unit 1-2)	3.77	0.41	-0.05	-5.240	.000	Exceeding Expectations
	Advanced Cycle (Unit 3-4)	3.82	0.40				Exceeding Expectations

These inferential outcomes empirically validate the central research hypothesis. They demonstrate that the Phenomenon-Based Transdisciplinary Boundary-Crossing (PB-TBC) instructional mechanism within the Transdisciplinary Learning Innovation does not generate arbitrary high scores, but instead systematically and securely drives a continuous, upward competency progression as learners confront increasingly complex transdisciplinary real-world modules.

4. Discussion and Conclusion

The development of the Transdisciplinary Learning Innovation, operationalized through the Phenomenon-Based Transdisciplinary Boundary-Crossing (PB-TBC) mechanism, demonstrates a transformative leap in secondary geography education. By systematically traversing the progressive domains of Geo-Knowledge, Geo-Process, Geo-Abilities, and Geo-Integration, this pedagogical innovation successfully elevated high school students' critical geo-literacy and spatial decision-making to the level of "Exceeding Expectations" ($\bar{x} = 3.82, S.D. = 0.40$).

Bridging Local Context with Global Educational Debates. While the historical evolution of the Thai geography curriculum reveals a recurring tension between state-centric nation-building and holistic competence, this study extends beyond a localized descriptive report. It bridges a critical gap in global educational debates regarding the role of geography in the modern era. Globally, geography education is plagued by structural fragmentation and systemic reliance on high-stakes testing, which inadvertently reduces a dynamic spatial science into passive data repositories. The transformation of Thai students into mere "rote memorizers" to secure higher education pathways directly mirrors the pedagogical dilemmas observed in diverse international contexts, where traditional curricula face significant opportunities to further enhance learners' cognitive tools necessary to decode complex human-environment interactions.

By shifting the paradigm from static spatial memorization to active, localized problem-solving (such as the PM 2.5 smog crisis), this research offers empirical evidence on how to break global patterns of academic fragmentation. The Transdisciplinary Learning Innovation proves that when geography is unchained from rigid subject silos, students transition from passive consumers of textbook facts into active spatial operators capable of navigating real-world environmental crises. Theoretical Deepening of Transdisciplinarity and Hypothesis Verification: to establish rigorous theoretical scaffolding, this study sharply distinguishes its pedagogical mechanism from weaker forms of curriculum integration. While multidisciplinary designs merely position subjects' side-by-side and interdisciplinary models blend boundaries, transdisciplinarity demands a radical transcendence of traditional disciplinary silos. It requires the co-production of socially robust knowledge driven by real-world problem-solving alongside non-academic stakeholders.

The structural effects of this transdisciplinary integration are validated across five core dimensions, providing robust support for our central hypotheses:

Geo-Knowledge (H1): Foundational spatial concepts and systematic branches are not discarded but treated as an essential first component. Elevating student understanding from raw concepts to technical applications significantly guides their subsequent problem-solving selection (Concepts ($\bar{x}$)= 3.84).

Geo-Process (H2): By implementing formal inquiry steps—from questioning to evaluation—students transcend static memorization and gain the procedural confidence to systematically decode spatial problems (Processes ($\bar{x}$)= 3.81).

Geo-Abilities (H3): Crucially, the innovation overcomes long-standing institutional constraints, such as the high cost and confidentiality of official maps, by deploying open-source GIS tools (QGIS and Google Earth Pro). This technical empowerment fosters a high level of cartographic confidence and systematic decision-making under uncertainty (Abilities ($\bar{x}$)= 3.80).

Geo-Integration (H4): Progressing from basic disciplinary infusion to advanced transdisciplinary synthesis forces a deep socio-spatial reconfiguration. Students successfully harmonized Science, Economics, and Social Studies into a unified analytical lens to address regional environmental threats.

Geo-Literacy (H5): This final stage represents the ultimate synthesis of advanced spatial reasoning and civic accountability. By establishing structured protocol dialogues with community mentors and local practitioners, the curriculum transforms geography into a concrete vehicle for green citizenship.

Inferential Rigor and Conceptual Discoveries: Statistical Validation: Inferential analysis utilizing a paired-samples t-test between the initial and advanced learning cycles demonstrates a statistically significant improvement in students' geo-literacy dimensions ($p < .05$). This inferential progression verifies that the PB-TBC mechanism systematically drives linear competency growth rather than generating arbitrary descriptive outcomes. Geo-Ethics and Spatial Justice: A prominent discovery of this study is that advanced geo-literacy must encompass ethical dimensions. Students did not merely gain technical GIS proficiency; they developed critical reflections regarding Spatial Justice—analyzing how urban planning policies and disaster management

infrastructures disproportionately impact marginalized socio-spatial groups—while strictly adhering to location data privacy. Reconfiguration of Media Ecology: The learning ecosystem redefines the role of contemporary learners within modern Media Ecology. Students transitioned from data consumers into public-facing data creators by publishing original “Toponym Podcasts” (spatial histories of local placenames) and designing infographic business models targeting PM 2.5 reduction.

Future suggestions and policy implication: To fully maximize the pedagogical potential of the Transdisciplinary Learning Innovation and ensure its long-term viability, a systematic reorientation addressing both practical implementation and macro-level educational policies is fundamentally required. Pedagogical Practice and Workload Sustainability: At the classroom level, implementing a transdisciplinary curriculum demands careful strategic planning to ensure instructional sustainability and prevent cognitive overload among both educators and learners. A highly effective mechanism to achieve this equilibrium is the adoption of a Single Project Evaluation framework. Rather than burdening students with fragmented assignments for every isolated subject, schools should implement cross-departmental rubric evaluations. Under this model, a singular, student-led comprehensive output—such as an environmental podcast or a spatial inquiry portfolio—can be concurrently assessed across multiple disciplines. For instance, the exact same project can be evaluated for spatial concepts in Geography, ecosystem mechanics in science, persuasive rhetoric in Language Arts, and digital media production in Computer Science. This collaborative grading synergy drastically reduces academic fatigue while reinforcing the interconnected nature of knowledge. Furthermore, consideration must be given to Instructional Scaffolding when expanding this framework from specialized cohorts, such as Geography Olympiad students, to general education classrooms. To successfully democratize these advanced competencies, instructors must provide targeted scaffolding, including simplified technical documentation, step-by-step guided protocols, and progressive video tutorials tailored for open source geoinformatics tools. Institutional and Curricular Policy Reorientation: On a broader scale, scaling up such innovations necessitates a profound structural transformation within institutional frameworks and national curricular policies. First, educational administrations must break away from the traditional, rigid constraints of 50-minute instructional blocks and transition toward modular, flexible formats such as “Project Weeks”. This temporal reorientation is vital to accommodate the intensive, non-linear demands of authentic geographical fieldwork and transdisciplinary synthesis that cannot be artificialized into compressed class periods. Second, a comprehensive Assessment Reformation must be enacted at the national policy level. National education frameworks must actively pivot away from high-stakes, memory-based multiple-choice examinations that inherently freeze geography education in passive rote memorization. Instead, standardized assessment metrics should heavily increase the weight of performance-based rubrics that directly evaluate multi-criteria Spatial Decision-Making and real-world problem-solving capabilities. Finally, true systemic equity cannot be achieved without the Democratization of Spatial Data. To eliminate entrenched socioeconomic disparities in technology and digital education, government agencies must establish progressive open-data policies. Providing public schools with unrestricted, cost-free access to high-resolution national geographic and cartographic datasets is a critical

prerequisite to fostering a digitally inclusive environment where every young learner can transform into an active spatial citizen.

In conclusion, this research presents an academic contribution to the field of sustainability and geography education. It addresses a severe global gap by operationalizing some concrete, clinically reproducible instructional innovation that successfully combats the universal “rote memorizer” dilemma. The Transdisciplinary Learning Innovation Comprehensive Instructional Package—complete with its modular teacher’s manual, open-source digital geoinformatics platform, and field-based learning protocols—stands as a highly scalable solution. It provides a transferable framework for global regions facing identical socio-environmental disruptions in the Anthropocene, demonstrating that boundary-crossing collaboration can successfully nurture the next generation of autonomous, critically literate spatial citizens.

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