CREATE: Contemporary Research in Education and Teaching **E-ISSN: 3164-8940**
Volume 1 | Issue 1 | 2026 https://doi.org/10.47945/create.v1i1.3357

Integrating STEM, Problem-Based Learning, and Satellite Imagery in Earth and Environmental Physics Education: A Systematic Literature Review

Gina Raudatu Jannah[a], **Wahyuni Bustami**[a]

[a]Department of Science Education, Institut Agama Islam Negeri Sorong, Indonesia

ABSTRACT

Earth and environmental education is expected to help students understand complex planetary systems, yet its instruction often remains abstract and disconnected from real spatial data. The integration of STEM, Problem-Based Learning (PBL), and satellite imagery is frequently proposed as a solution, but the empirical basis for integrating all three components has not been systematically examined. This systematic literature review, reported with reference to PRISMA 2020, addresses three questions: how the three components are configured in practice, what outcomes are reported for spatial thinking, systems thinking, and conceptual understanding, and what evidence gaps remain. Peer-reviewed journal articles published from 2016–2026 were searched through Google Scholar, screened according to eligibility criteria, and analyzed through configuration mapping, thematic synthesis, and descriptive comparisons of reported statistics. Eight studies from Indonesia were included. None of the studies integrated all three components. The most frequent configuration was PBL combined with Google Earth imagery (three studies), and only one study explicitly operationalized a STEM design with an engineering component. Spatial thinking was the most frequently measured outcome, and experimental groups were reported to outperform comparison groups (mean posttest scores of 91.00 vs. 81.39 and 85.64 vs. 74.08; N-gain of 0.52 vs. 0.37). No study measured systems thinking, reported standardized effect sizes, or assessed retention. Several studies also used small samples, designs without control groups, or statistical tests whose appropriateness is questionable. Therefore, this review supports only the cautious conclusion that satellite-imagery-supported PBL is associated with improved spatial thinking. The claim that full STEM–PBL–satellite imagery integration improves systemic problem solving remains untested. This review also proposes a conceptual framework and research agenda to guide more rigorous future studies.

Keywords: STEM Integration; Problem-Based Learning; Satellite Imagery; Spatial Thinking

Correspondence: nanaaa250500@gmail.com | **Copyright:** This open access article is distributed under a CC BY-SA License
Article History: Received: 14 April 2026 | Accepted: 12 May 2026 | **Homepage**: https://e-jurnal.iainsorong.ac.id/index.php/great
Citation: Jannah, G. R., & Bustani, W. (2026). Integrating STEM, Problem-Based Learning, and Satellite Imagery in Earth and Environmental Physics Education: A Systematic Literature Review. CREATE: Contemporary Research in Education and Teaching, 1(1), 18–31. https://doi.org/10.47945/create.v1i1.3357

I. INTRODUCTION

Land-cover change, hydrometeorological disasters, and climate change require citizens who are able to understand the Earth as an interconnected system. Such understanding cannot be adequately developed through memorization of decontextualized physical laws, because Earth phenomena involve interactions among the atmosphere, hydrosphere, lithosphere, and biosphere across broad spatial and temporal scales. Research on Earth system education shows that systems thinking develops gradually and hierarchically, beginning with recognizing system components, identifying dynamic relationships among components, and progressing to an understanding of system cycles and temporal dimensions (Assaraf & Orion, 2005). In that study, only about one-third of eighth-grade students reached the highest level of systems thinking on the topic of the hydrological cycle, and students' progress was influenced by their engagement in knowledge-integration activities both inside and outside the classroom. These findings underscore that Earth science education requires designs that deliberately connect data, concepts, and contexts.

Satellite imagery offers one of the most promising bridges between abstract concepts and these spatial realities. Dannwolf et al. (2020) showed that the use of Earth observation imagery in schools can increase students' awareness of global issues such as urbanization, biodiversity loss, environmental disasters, and food security. Student-centered approaches that make use of such data have also been associated with increased motivation and specific competencies, including spatial thinking. However, the same study identified two major barriers: limited teacher technological–pedagogical knowledge specific

to Earth observation and insufficient equipment in schools. These barriers are relevant to Indonesia, where disparities in digital infrastructure across regions remain a concern.

Spatial thinking provides another important rationale for using satellite imagery. Large-scale longitudinal research has shown that spatial ability predicts achievement and participation in STEM fields beyond the contributions of verbal and mathematical abilities (Wai et al., 2009). Encouragingly, this ability can be trained: a meta-analysis of 217 training studies found a mean effect of $g = 0.47$, with effects remaining stable after delays and transferring to other spatial tasks (Uttal et al., 2013). In geography education, Jo dan Bednarz (2009) formulated a taxonomy of spatial thinking that integrates concepts of space, tools of representation, and cognitive processes. This taxonomy is useful for assessing whether a task genuinely requires spatial reasoning or merely map recognition. At the same time, students often experience difficulties with maps and other spatial representations, including translating two-dimensional representations into three-dimensional structures (Ishikawa & Kastens, 2005). Therefore, the presence of satellite imagery in the classroom does not automatically produce understanding; it may instead increase cognitive demands if students are not taught how to interpret it.

STEM integration provides a framework for positioning spatial data within meaningful learning activities. Kelley dan Knowles (2016) proposed an integrated STEM framework grounded in situated learning, with scientific inquiry, engineering design, technological literacy, and mathematical thinking as mutually supporting components. However, the term STEM is used in diverse ways in the literature. The review by Martín-Páez et al. (2019) indicates that the meaning and implementation of STEM education remain inconsistent, while English (2016) distinguishes multidisciplinary, interdisciplinary, and transdisciplinary integration and notes that mathematics and engineering are often less represented than science. Evidence of its effectiveness is now substantial: a meta-analysis of 124 studies found a moderate effect on knowledge acquisition and moderate-to-large effects on cognitive skills, with task type (inquiry vs. design) and program duration serving as important moderators (Chen et al., 2026). Nevertheless, teachers report various pedagogical, curricular, and structural barriers to implementing STEM, as well as a need for support and professional development (Margot & Kettler, 2019).

Problem-Based Learning (PBL) complements this framework with a clear pedagogical structure. PBL is a student-centered approach that begins with an ill-structured problem, requires independent and collaborative inquiry, and concludes with reflection on the learning process (Savery, 2006). Ill-structured problems require students to integrate knowledge from multiple domains and consider multiple possible solutions (Jonassen, 2000), making this characteristic consistent with the complexity of environmental issues. Hmelo-Silver (2004) explains that PBL is designed to develop flexible knowledge, problem-solving skills, self-directed learning, and collaboration. Evidence of its effectiveness varies by outcome: Dochy et al. (2003) found a strong positive effect on skills but a tendency toward negative effects on knowledge. Strobel dan van Barneveld (2009) reported advantages of PBL for long-term retention and skill development. At the K–8 level, Merritt et al. (2017) concluded that PBL effectively improves science academic achievement, including knowledge retention and conceptual development, although definitions of PBL are not consistent across studies.

Combining PBL with complex data also raises issues of cognitive load. Problem solving without adequate guidance can exhaust working-memory capacity and hinder schema formation (Sweller, 1988). On this basis, Kirschner et al. (2006) criticized minimally guided instruction. Hmelo-Silver et al. (2007) responded to this criticism by emphasizing that well-designed PBL provides intensive scaffolding. The meta-analysis by Lazonder dan Harmsen (2016) supports this middle position: guidance enhances learning activities, performance, and learning outcomes in inquiry-based learning. In group work, cognitive load is also influenced by the coordination costs among members (Kirschner et al., 2018). Meanwhile, satellite imagery is a representation that requires an understanding of form, color

conventions, and relationships with other representations. The DeFT framework explains that multiple representations are beneficial only when students are able to understand each representation and connect them to one another (Ainsworth, 2006).

Thus, theoretically, the three components are complementary. PBL provides the problem context and inquiry structure, satellite imagery provides authentic data and a spatial representation tool, while STEM provides an integrative framework incorporating engineering design and mathematical modeling. However, research on geospatial technologies in learning remains limited, fragmented, and inconclusive, and has not distinguished between learning with geospatial technologies and learning about such technologies (Baker et al., 2015). GIS-based learning has been associated with improved spatial thinking among university students (Lee & Bednarz, 2009). A recent international systematic review of STEM-based geography education also identifies GIS, remote sensing, and GPS as core tools, but notes the absence of a comprehensive methodological framework and the concentration of research in particular countries (Seminar et al., 2026). In Indonesia, a review of spatial-thinking assessment over a decade found that most researchers developed their own instruments, with a narrow focus on the spatial-relations dimension (Al-Bukhori & Purwanto, 2025).

This synthesis points to three gaps. First, there is a conceptual gap: claims concerning "STEM–PBL–satellite imagery integration" are often made without clarifying which STEM components are actually operationalized. Second, there is an empirical gap: it remains unclear whether the expected outcomes, particularly spatial thinking and systemic problem solving, are actually measured and whether they are assessed using adequate research designs. Third, there is a contextual gap: international reviews relying solely on Scopus have limited access to evidence from Indonesia, where relevant studies are commonly published in national journals (Seminar et al., 2026). To the best of the authors' knowledge, no systematic review has yet mapped the intersection of these three components in Earth and environmental physics education in Indonesia. Therefore, this review addresses three research questions (RQs). RQ1: How are the integration configurations of STEM, PBL, and satellite imagery/geospatial technology operationalized in Earth and environmental learning studies? RQ2: What outcomes are reported for spatial thinking, systems thinking or problem solving, and conceptual understanding, and how strong is the evidence? RQ3: What gaps need to be addressed by future research? The contributions of this review include mapping evidence within the Indonesian context, critically assessing the strength of the evidence, and proposing a testable conceptual framework.

II. RESEARCH METHODS

This study is a systematic literature review reported with reference to the PRISMA 2020 guidelines (Page et al., 2021). These guidelines were used to ensure that each stage, from identification through synthesis, was reported transparently so that the process could be examined and replicated.

The inclusion criteria were: (1) published in 2016–2026; (2) peer-reviewed journal articles; (3) written in Indonesian or English; (4) focused on Earth science, geoscience, physical geography, Earth physics, or environmental education at primary, secondary, or higher-education levels; and (5) implemented or analyzed at least one of the three components, namely STEM integration, PBL, or satellite imagery/geospatial technology. The fifth criterion was intentionally formulated inclusively so that the review could map component configurations, including identifying whether or not studies integrating all three components exist. Exclusion criteria included conference proceedings, book chapters, undergraduate theses/master's theses/doctoral dissertations, technical reports, articles outside the educational context (pure remote-sensing studies), and articles for which the full text was inaccessible.

The search was conducted through Google Scholar on 10–26 June 2026. The search string was constructed using Boolean operators and developed incrementally following a systematic approach to

search-strategy development (Bramer et al., 2018): ("STEM" OR "integrasi STEM") AND ("problem based learning" OR "PBL" OR "pembelajaran berbasis masalah") AND ("citra satelit" OR "satellite imagery" OR "penginderaan jauh" OR "remote sensing" OR "Google Earth" OR "SIG" OR "GIS") AND ("geografi" OR "kebumian" OR "geosains" OR "lingkungan" OR "fisika bumi"). Because Google Scholar has limitations in reproducibility and Boolean functionality as a primary source for systematic reviews (Gusenbauer & Haddaway, 2020), this limitation is explicitly reported as a limitation of the study.

Selection was conducted in four stages in accordance with the PRISMA 2020 flow diagram: removal of duplicates, title and abstract screening, full-text eligibility assessment, and determination of the included studies (Table 1). Screening was conducted by two reviewers through confirmation and in-depth examination of the sources analyzed.

Table 1. Summary of the study selection process based on PRISMA 2020

PRISMA 2020 Stage	Number	Notes
Identification: records from Google Scholar	26	Search date: 11 June 2026; publication-year limit: 2016–2026
Records removed before screening	9	Metadata completeness and duplication
Title and abstract screening	17	4 excluded because they were outside the specific scope
Full-text eligibility assessed	13	5 excluded because of methodological and content-related ineligibility
Studies included in the synthesis	8	Empirical: 7; literature review: 1

The methodological quality of empirical studies was assessed using the Mixed Methods Appraisal Tool (MMAT) version 2018, which provides separate criteria for qualitative, randomized quantitative, non-randomized quantitative, quantitative descriptive, and mixed-methods designs (Hong et al., 2018). The assessment focused on design clarity, sample representativeness, instrument validity and reliability, control of confounding variables, and the appropriateness of statistical analyses. The literature review study was not assessed using MMAT and was used only to map component configurations.

Data were extracted using a standardized matrix containing study identity, context and topic, design, sample, implemented components, instruments, outcomes, reported statistics, and the presence of follow-up measurements. Component and outcome coding was conducted deductively using the operational definitions in Table 2, which were developed based on the integrated STEM framework (Kelley & Knowles, 2016), the definition of PBL (Savery, 2006), the spatial-thinking taxonomy (Jo & Bednarz, 2009), and the systems-thinking model (Assaraf & Orion, 2005). Synthesis was conducted at three levels: (1) mapping component configurations to address RQ1; (2) thematic synthesis involving coding of findings, development of descriptive themes, and formulation of analytical themes (Thomas & Harden, 2008), accompanied by descriptive comparisons of the reported statistics to address RQ2; and (3) identification of gaps to address RQ3. A meta-analysis was not conducted because no study reported standardized effect sizes, and most abstracts did not provide the standard deviations required to calculate.

Table 2. Framework for Coding Components And Outcomes

Code Category	Operational Definition	Indicators In Study Texts
Integrated STEM	Learning that explicitly connects at least two STEM disciplines through an authentic problem, with scientific inquiry, engineering design, technological literacy, and/or mathematical thinking (Kelley & Knowles, 2016)	STEM syntax, prototype design, quantitative modeling
Engineering component	Students design, test, and refine solutions	Prototype, design cycle
Mathematics component	Students conduct measurements, calculations, or quantitative modeling of data	Area/rate-of-change calculations, statistical analysis of spatial data

Code Category	Operational Definition	Indicators In Study Texts
PBL	Student-centered learning that begins with an ill-structured problem, involving individual/group inquiry and reflection (Savery, 2006)	Problem orientation–investigation–presentation–evaluation sequence
Satellite imagery technology	Use of remote-sensing imagery or geospatial platforms as data sources or analytical media	Google Earth, Google Earth Engine, Landsat, Sentinel, WebGIS
Spatial thinking	The ability to use concepts of space, tools of representation, and spatial reasoning processes (Jo & Bednarz, 2009)	Spatial-thinking tests, distribution-pattern analysis
Systems thinking	The ability to identify components, dynamic relationships, cycles, and temporal dimensions of an Earth system (Assaraf & Orion, 2005)	Systems concept maps, prediction and retrospection tasks
Conceptual understanding outcomes	Mastery of Earth or environmental concepts measured through tests	Posttest scores, N-gain

III. RESULTS AND DISCUSSION

Eight studies met the criteria (Table 3), comprising seven empirical studies and one literature review. All studies originated from Indonesia and were published between 2019 and 2025. Seven studies were situated in high-school geography education, and one study was situated in a geoscience course for prospective elementary school teachers. No study explicitly focused on physics as a subject or addressed Earth physics concepts such as radiative equilibrium, atmospheric thermodynamics, or fluid dynamics. The empirical designs varied: experimental or quasi-experimental designs with comparison groups (three studies), classroom action research (one study), a one-group pre-experimental design (one study), development research (one study), and one quantitative study whose design was not described in detail in the abstract.

Table 3. Characteristics and main findings of the included studies

Study	Context & topic	Design & sample	Components	Main findings reported
Ardianto et al. (2019)	Geoscience course, elementary teacher education	Development research, 25 prospective primary school teachers	STEM (STEM-FC) + engineering	The STEM-FC design facilitated active learning; students' enthusiasm for geoscience content increased
Nurcahyo & Winanti (2021)	High-school geography; disaster mitigation	Quasi-experiment; Grade XI Social Sciences class at SMA N 2 Ponorogo	PBL (+ inductive approach)	*Spatial-thinking N-gain 0.52 (experimental) vs. 0.37 (control); knowledge 0.58 vs. 0.43; sig. t-test*
Buana & Putra (2023)	High-school geography; disaster distribution	Kemmis–Taggart classroom action research, 2 cycles.	PBL + WebGIS (InaRISK)	Spatial-thinking ability increased in each cycle; measured using a five-item test
Suasti & Shafira (2025)	High-school geography; SMA N 2 Pariaman	Experiment; two Grade XI classes (purposive)	PBL + Google Earth	Mean posttest 91.00 vs. 81.39 (conventional maps); $p = 0.001$ (paired-sample t-test)
Suasti & Aini (2025)	High-school geography; SMA N 5 Bukittinggi	Experiment; two Grade XI classes (purposive)	PBL + Google Earth	Mean posttest 85.64 vs. 74.08; $p = 0.001$ (paired-sample t-test)
Salam et al. (2023)	High-school geography; SMA N 2 Gorontalo	Quantitative, t-test	Google Earth imagery	Significance 0.030 (< 0.05); Google Earth imagery was stated to affect spatial thinking
Muhammad (2025)	High-school geography; remote sensing, GIS	One-group pre-experimental pretest–posttest;	Satellite imagery (Google Earth Engine)	Understanding of the SDGs and remote-sensing technology increased by 11%
Gadeng et al. (2022)	High-school geography; remote sensing	Literature review	Remote sensing (software, UAVs, image interpretation)	Recommends traditional innovations and modern approaches; teachers required to be technologically literate

The configuration mapping (Table 4) produced the key finding that none of the studies integrated all three components—STEM, PBL, and satellite imagery. The most frequent configuration was PBL combined with geospatial technology (three studies), particularly Google Earth (Suasti & Aini, 2025; Suasti & Shafira, 2025) and WebGIS InaRISK (Buana & Putra, 2023). Three studies used satellite imagery or remote sensing without PBL or STEM (Gadeng et al., 2022; Muhammad, 2025; Salam et al., 2023). One study implemented PBL without an explicit explanation of satellite-imagery use (Nurcahyo & Winanti, 2021), and one study implemented a STEM design without satellite imagery (Ardianto et al., 2019).

STEM components were explicitly operationalized in only one study, and only that study included an engineering element. In studies using PBL supported by satellite imagery, the technology dimension was present through platform use, but there was no indication that students performed mathematical modeling of image data, such as calculating rates of change in land area or analyzing time series. Students also did not design engineering solutions. In other words, the term "STEM integration" in this context is more appropriately understood as the use of technology within PBL rather than interdisciplinary or transdisciplinary integration as formulated by English (2016). The only study that used operational satellite data (Landsat 8 and Sentinel) through Google Earth Engine did not use a PBL syntax or STEM framework (Muhammad, 2025).

Table 4. Matrix of component configurations in the included studies

Study	STEM	PBL	Satellite	Engineering Component	Explicit Context
Ardianto et al. (2019)	Yes	—	—	Yes	Yes
Nurcahyo & Winanti (2021)	—	Yes	Yes	—	—
Buana & Putra (2023)	—	Yes	Yes	—	—
Suasti & Shafira (2025)	—	Yes	Yes	—	—
Suasti & Aini (2025)	—	Yes	Yes	—	—
Salam et al. (2023)	—	—	Yes	—	—
Muhammad (2025)	—	—	Yes	—	—
Gadeng et al. (2022)	—	—	Yes	—	—
Total	1	4	6	1	0

Note: "Yes" = the component was explicitly reported; "—" = not reported; [?] = could not yet be determined from the abstract and requires examination of the full text.

Spatial thinking was the most frequently measured outcome (five studies), and all studies reported favorable results for the treatment groups. Two experimental studies comparing PBL supported by Google Earth with learning using conventional maps reported mean posttest scores of 91.00 vs. 81.39 (Suasti & Shafira, 2025) and 85.64 vs. 74.08 (Suasti & Aini, 2025), respectively, with $p = 0.001$. A quasi-experimental study integrating PBL with an inductive approach reported spatial-thinking N-gain values of 0.52 in the experimental class and 0.37 in the control class (Nurcahyo & Winanti, 2021). A classroom action research study combining PBL with WebGIS InaRISK reported increases in spatial thinking across each cycle using a five-item instrument (Buana & Putra, 2023). Another study concluded that Google Earth imagery affected students' spatial thinking based on a t-test with a significance value of 0.030 (Salam et al., 2023).

Two studies reported knowledge outcomes. The PBL class obtained an N-gain of 0.58 for disaster-mitigation knowledge, compared with 0.43 in the control class (Nurcahyo & Winanti, 2021). Satellite-imagery-based SDGs learning increased understanding by 11% among ten students (Muhammad, 2025). In terms of engagement, the STEM-FC design was reported to facilitate active learning and increase students' enthusiasm for geoscience content (Ardianto et al., 2019), but the study did not quantitatively measure cognitive outcomes.

No study measured systems thinking or systemic problem solving, although these abilities are often claimed to be major advantages of integrating PBL and satellite imagery. This finding is important because claims about impacts on systems thinking, which commonly appear in learning-development narratives, lack empirical support in the reviewed corpus.

Table 5 summarizes the strength of the evidence. No study reported standardized effect sizes or conducted retention measurements. Two of the seven empirical studies did not use comparison groups, one of which involved only ten students. Two experimental studies reported using paired-sample t-tests to compare the experimental and control classes. If the comparison involved two different groups, an independent-samples test or analysis of covariance with the pretest as a covariate would be more appropriate. Therefore, the statistical conclusions should be interpreted cautiously until the analytical procedures can be verified in the full texts. In addition, the designs of the Google Earth-supported PBL studies did not separate the effects of the model (PBL) from those of the medium (Google Earth), because the control classes used conventional maps. Consequently, the observed improvement cannot be attributed definitively to either one.

Table 5. Matrix Of The Strength Of Evidence For Empirical Studies

Study	Outcomes	Comparison group	Standardized effect size	Retention	Methodological notes
Nurcahyo & Winanti (2021)	Spatialthinking; knowledge	Yes	No (N-gain)	No	Sample size not stated in the abstract
Buana & Putra (2023)	Spatial thinking	No (CAR)	No	No	Unable to separate intervention effects from maturation and testing effects
Suasti & Shafira (2025)	Spatial thinking	Yes	No	No	Paired test used to compare two independent groups
Suasti & Aini (2025)	Spatial thinking	Yes	No	No	Same as S4
Salam et al. (2023)	Spatial thinking	No	No	No	Design not described in the abstract
Muhammad (2025)	remote-sensing understanding	No	No	No	n = 10; no control group
Ardianto et al. (2019)	Engagement, enthusiasm	No	No	No	Design trial; cognitive outcomes were not measured

Why the Integration of the Three Components Has Not Yet Been Achieved

The finding that no study integrated all three components indicates a gap between rhetoric and practice. At least three explanations can be proposed. First, STEM integration requires cross-disciplinary competencies that are not easily met by teachers. A systematic review of teachers' perceptions shows that teachers value STEM but face pedagogical, curricular, and structural barriers and require professional-development support (Margot & Kettler, 2019). Second, the use of satellite imagery requires specific technological–pedagogical–content knowledge. The TPACK framework emphasizes that meaningful technology integration requires the combination of knowledge about technology, pedagogy, and content, rather than mere mastery of tools (Mishra & Koehler, 2006), while Dannwolf et al. (2020) noted that Earth-observation-specific TPACK is not yet common knowledge among teachers. Third, disciplinary imbalance within STEM, namely the weak representation of engineering and mathematics (English, 2016), is clearly evident in this corpus: only one study included engineering, and no study included mathematical modeling of image data.

The contextual findings are also important. All studies using satellite imagery were situated in geography education, whereas no study was situated in physics education. This indicates that the potential of satellite imagery for teaching Earth and environmental physics concepts has not yet been explored in

this corpus. However, a national meta-analysis reported that STEM approaches in physics education had a high reported effect on conceptual understanding and creative-thinking skills (Putra et al., 2023). The large effect sizes in that meta-analysis, which exceeded 2 and even 6 in some subgroups, should be interpreted cautiously because they were derived from 20 articles with potentially high heterogeneity. This can be contrasted with the moderate effect reported by the large-scale international meta-analysis (Chen et al., 2026).

Interpreting the Increase in Spatial Thinking

The consistency of findings on spatial thinking is aligned with evidence that spatial ability can be trained (Uttal et al., 2013) and that GIS-based learning is associated with improved spatial thinking (Lee & Bednarz, 2009). Satellite imagery provides a rich visual context for practicing spatial concepts such as location, pattern, distribution, and change, thereby theoretically supporting the three elements of the Jo dan Bednarz (2009) taxonomy. Nevertheless, at least three factors limit the strength of this interpretation. First, the instruments used were generally developed by the researchers themselves, often consisted of only a few items, and did not report their relationship to specific spatial-thinking dimensions. This issue is consistent with the finding of Al-Bukhori dan Purwanto (2025) that spatial-thinking research in Indonesia is dominated by researcher-developed instruments focused on spatial relationships, while research conclusions tend to be similar despite differences in the instruments. This pattern may indicate validity concerns. Second, the novelty effect of the medium should be considered. Clark (1983) argued that media are merely vehicles for delivery and that some advantages reported in media studies may derive from instructional methods or novelty effects that diminish over time. The studies in this corpus were short in duration and did not conduct follow-up measurements, so the possibility of a novelty effect cannot yet be ruled out. Third, as noted above, the existing designs confound the effects of the model and the medium. A factorial design comparing PBL with and without satellite imagery would be more informative.

Systems Thinking: A Theoretical Promise Yet to Be Tested

The absence of systems-thinking measurement represents the most fundamental gap. Multitemporal satellite imagery is highly suitable for developing higher-order systems-thinking components in the Assaraf dan Orion (2005) model, particularly the temporal dimension (retrospection and prediction) and the identification of dynamic relationships, such as between changes in upstream land cover and downstream inundation. However, the model also shows that higher-order abilities develop only after basic abilities, such as identifying components and simple relationships, have been established. Without explicitly designed knowledge-integration activities, higher-order abilities do not emerge automatically. Therefore, future research should use systems-thinking instruments that have been applied in Earth system education and assess student development by level rather than relying solely on total scores.

Cognitive Load and the Need for Scaffolding

Satellite imagery, particularly false-color composites and multispectral data, represents a non-intuitive form of representation for beginners. The DeFT framework reminds us that multiple representations require students to understand the form of each representation, the relationship between the representation and the domain, and the relationships among representations (Ainsworth, 2006). Students' difficulties with maps and spatial representations (Ishikawa & Kastens, 2005) demonstrate that these demands are real. When combined with ill-structured problems and group work, the total cognitive load may exceed working-memory capacity (Kirschner et al., 2018; Sweller, 1988). The implication is that satellite-imagery-supported PBL requires planned scaffolding, such as image-interpretation keys, worked examples, and group-role allocation. This need is consistent with meta-analytic evidence on the

importance of guidance (Lazonder & Harmsen, 2016) and the scaffolded nature of PBL (Hmelo-Silver et al., 2007). The recommendation by Gadeng et al. (2022) that teachers combine field activities and image interpretation with software can be understood as an effort to provide a bridge between concrete experience and abstract representation.

Proposed Conceptual Framework

Based on this synthesis, this review proposes a conceptual framework mapping the roles of satellite imagery and STEM components across each phase of PBL (Table 6). This framework is a theoretical proposal derived from the literature, rather than an empirical result, and needs to be tested through design-based or experimental research. Three principles underlie it. First, satellite imagery functions as a source of authentic data rather than merely as an illustration, consistent with the distinction between learning with and learning about geospatial technology (Baker et al., 2015). Second, engineering and mathematics components are introduced explicitly through measurement, modeling, and solution design, in accordance with the integrated STEM framework (Kelley & Knowles, 2016). Third, scaffolding is adapted to the representational demands of each phase (Ainsworth, 2006; Hmelo-Silver et al., 2007). In the context of environmental physics, this framework can be applied, for example, to problems involving land-cover change and its effects on water runoff or surface temperature, with physical concepts and image channels adjusted to the learning objectives.

Table 6. Proposed STEM–PBL–Satellite Imagery Integration Framework

PBL phase	Role of satellite imagery	STEM components activated	Recommended scaffolding	Targeted outcomes
Problem orientation	Multitemporal imagery as a trigger for a local problem	Science: physical phenomena involved	Prompting questions	Problem identification
Learning organization	Determination of the study area and required data	Technology: platform selection and image channels	Brief interface tutorial; group-role allocation	Geospatial technology literacy
Investigation	Interpretation of true-color and composite imagery; measurement of area, distance, and change	Mathematics: measurement, rate of change, time-series graphs	Interpretation key; worked example	Spatial thinking (spatial concepts, representation, reasoning)
Solution development	Mapping risk zones and intervention alternatives	Engineering: design & testing of mitigation solutions	Design criteria; peer feedback	Problem solving; systems thinking (dynamic relation)
Evaluation and reflection	Comparison of predictions with data	Integration of all four components	Systems reflection rubric	Systems thinking metacognition

Comparison with International Evidence

Compared with the international literature, this corpus shows both similar and different patterns. The review by Seminar et al. (2026) also found that STEM in geography education was associated with improved inquiry skills, problem solving, motivation, and spatial thinking. That review also noted the absence of a comprehensive methodological framework for STEM–geography integration. A study of immersive-technology-based environmental learning showed that exploring virtual spatial environments was associated with knowledge acquisition about climate change (Markowitz et al., 2018). This finding suggests that active engagement within representational spaces, rather than mere visual exposure, is a mechanism that warrants attention. In contrast, evidence from Indonesia is still dominated by small-scale studies with weak designs and narrow outcomes. Consequently, its contribution to the international evidence base remains limited unless strengthened by more rigorous designs.

Research Agenda and Practical Implications

Based on the identified gaps, future research should: (1) design and test interventions that genuinely integrate all three components, with explicit engineering components and mathematical modeling; (2) measure systems thinking using instruments based on hierarchical models and spatial thinking using instruments mapped onto a clear taxonomy and tested for validity and reliability; (3) use designs with comparison groups that separate the effects of the model and medium, report means, standard deviations, and effect sizes, and conduct delayed measurements to examine retention and novelty effects; (4) extend the context to physics and science education, rather than geography alone; and (5) investigate teachers' professional-development needs related to Earth-observation TPACK and solutions for schools with limited infrastructure, such as offline modules or learning centers outside schools (Dannwolf et al., 2020).

In practical terms, teachers who wish to use satellite imagery in PBL are advised to begin with accessible platforms such as Google Earth. Teachers should also provide interpretation keys and scaffolded tasks, and deliberately incorporate measurement and solution-design activities so that the mathematical and engineering dimensions are not lost. Claims about improvements in systems thinking should not be made without appropriate assessment.

This review has several limitations. The search used only Google Scholar (Gusenbauer & Haddaway, 2020), so relevant studies in other databases may have been missed. The number of studies meeting the criteria was small, and all were from Indonesia. Some design and statistical information could not be confirmed from the abstracts and requires examination of the full texts. In addition, the absence of effect sizes precluded a meta-analysis. Therefore, the findings of this review are mapping-oriented and cannot be generalized as estimates of effectiveness

IV. CONCLUSION

This review addressed three research questions. For RQ1, no study in the corpus integrated STEM, PBL, and satellite imagery simultaneously. The dominant configuration was PBL supported by Google Earth or WebGIS, while engineering components and mathematical modeling were largely absent, and all studies were situated in geography education rather than physics. For RQ2, the existing studies consistently reported improvements in spatial thinking and conceptual understanding. However, the strength of the evidence remains limited because of small sample sizes, the absence of comparison groups in some designs, unreported effect sizes, the lack of retention measurements, and the failure to separate the effects of the model from those of the medium. Systems thinking was not measured at all. For RQ3, the main gaps include the absence of full integration, weak engineering and mathematics components, the lack of standardized instruments for spatial thinking and systems thinking, limitations in research design, and the need to develop teacher competencies. Thus, STEM–PBL–satellite imagery integration is theoretically promising. However, its impact on systemic problem solving in Earth and environmental physics education has not yet been tested and needs to be established through more rigorous research, with the proposed conceptual framework serving as a starting point.

V. REFERENCE

Ainsworth, S. (2006). DeFT: A conceptual framework for considering learning with multiple representations. *Learning and Instruction, 16*(3), 183–198. https://doi.org/10.1016/j.learninstruc.2006.03.001

Al-Bukhori, L. A., & Purwanto, P. (2025). Mempertanyakan sepuluh tahun pengukuran kemampuan berpikir spasial dalam penelitian pendidikan geografi di Indonesia (2013–2023). *Ganaya: Jurnal Ilmu Sosial dan Humaniora, 8*(1), 349–372. https://doi.org/10.37329/ganaya.v8i1.3765

Ardianto, D., Permanasari, A., Firman, H., & Ramalis, T. R. (2019). Desain model STEM-FC pada perkuliahan geosains. *Journal of Science Education and Practice, 3*(1), 48–57. https://doi.org/10.33751/jsep.v3i1.2738

Assaraf, O. B.-Z., & Orion, N. (2005). Development of system thinking skills in the context of earth system education. *Journal of Research in Science Teaching, 42*(5), 518–560. https://doi.org/10.1002/tea.20061

Baker, T. R., Battersby, S., Bednarz, S. W., Bodzin, A. M., Kolvoord, B., Moore, S., Sinton, D., & Uttal, D. (2015). A research agenda for geospatial technologies and learning. *Journal of Geography, 114*(3), 118–130. https://doi.org/10.1080/00221341.2014.950684

Bramer, W. M., de Jonge, G. B., Rethlefsen, M. L., Mast, F., & Kleijnen, J. (2018). A systematic approach to searching: An efficient and complete method to develop literature searches. *Journal of the Medical Library Association, 106*(4), 531–541. https://doi.org/10.5195/jmla.2018.283

Buana, R. T., & Putra, A. K. (2023). Peningkatan kemampuan berpikir spasial: Implementasi model problem based learning melalui pendekatan self efficacy berbantuan WebGIS InaRISK. *Journal of Education Action Research, 7*(3), https://doi.org/10.23887/jear.v7i3.63881

Chen, B., Chen, J., Wang, M., Tsai, C.-C., & Kirschner, P. A. (2026). The effects of integrated STEM education on K12 students' achievements: A meta-analysis. *Review of Educational Research, 96*(2), 619–668. https://doi.org/10.3102/00346543251318297

Clark, R. E. (1983). Reconsidering research on learning from media. *Review of Educational Research, 53*(4), 445–459. https://doi.org/10.3102/00346543053004445

Dannwolf, L., Matusch, T., Keller, J., Redlich, R., & Siegmund, A. (2020). Bringing Earth observation to classrooms—The importance of out-of-school learning places and e-learning. *Remote Sensing, 12*(19), Article 3117. https://doi.org/10.3390/rs12193117

Dochy, F., Segers, M., Van den Bossche, P., & Gijbels, D. (2003). Effects of problem-based learning: A meta-analysis. *Learning and Instruction, 13*(5), 533–568. https://doi.org/10.1016/S0959-4752(02)00025-7

English, L. D. (2016). STEM education K-12: Perspectives on integration. *International Journal of STEM Education, 3*, Article 3. https://doi.org/10.1186/s40594-016-0036-1

Gadeng, A. N., Urfan, F., Himayah, S., Furqan, M. H., Desfandi, M., & Azis, D. (2022). Inovasi pembelajaran geografi untuk materi penginderaan jauh di sekolah menengah atas. *Majalah Geografi Indonesia, 36*(2), 148–157. https://doi.org/10.22146/mgi.64988

Gusenbauer, M., & Haddaway, N. R. (2020). Which academic search systems are suitable for systematic reviews or meta-analyses? Evaluating retrieval qualities of Google Scholar, PubMed, and 26 other resources. *Research Synthesis Methods, 11*(2), 181–217. https://doi.org/10.1002/jrsm.1378

Hmelo-Silver, C. E. (2004). Problem-based learning: What and how do students learn? *Educational Psychology Review, 16*(3), 235–266. https://doi.org/10.1023/B:EDPR.0000034022.16470.f3

Hmelo-Silver, C. E., Duncan, R. G., & Chinn, C. A. (2007). Scaffolding and achievement in problem-based and inquiry learning: A response to Kirschner, Sweller, and Clark (2006). *Educational Psychologist, 42*(2), 99–107. https://doi.org/10.1080/00461520701263368

Hong, Q. N., Fàbregues, S., Bartlett, G., Boardman, F., Cargo, M., Dagenais, P., Gagnon, M.-P., Griffiths, F., Nicolau, B., O'Cathain, A., Rousseau, M.-C., Vedel, I., & Pluye, P. (2018). The Mixed Methods Appraisal Tool (MMAT) version 2018 for information professionals and researchers. *Education for Information, 34*(4), 285–291. https://doi.org/10.3233/EFI-180221

Ishikawa, T., & Kastens, K. A. (2005). Why some students have trouble with maps and other spatial representations. *Journal of Geoscience Education, 53*(2), 184–197. https://doi.org/10.5408/1089-9995-53.2.184

Jo, I., & Bednarz, S. W. (2009). Evaluating geography textbook questions from a spatial perspective: Using concepts of space, tools of representation, and cognitive processes to evaluate spatiality. *Journal of Geography, 108*(1), 4–13. https://doi.org/10.1080/00221340902758401

Jonassen, D. H. (2000). Toward a design theory of problem solving. *Educational Technology Research and Development, 48*(4), 63–85. https://doi.org/10.1007/BF02300500

Kelley, T. R., & Knowles, J. G. (2016). A conceptual framework for integrated STEM education. *International Journal of STEM Education, 3*, Article 11. https://doi.org/10.1186/s40594-016-0046-z

Kirschner, P. A., Sweller, J., & Clark, R. E. (2006). Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. *Educational Psychologist, 41*(2), 75–86. https://doi.org/10.1207/s15326985ep4102_1

Kirschner, P. A., Sweller, J., Kirschner, F., & Zambrano R., J. (2018). From cognitive load theory to collaborative cognitive load theory. *International Journal of Computer-Supported Collaborative Learning, 13*(2), 213–233. https://doi.org/10.1007/s11412-018-9277-y

Lazonder, A. W., & Harmsen, R. (2016). Meta-analysis of inquiry-based learning: Effects of guidance. *Review of Educational Research, 86*(3), 681–718. https://doi.org/10.3102/0034654315627366

Lee, J., & Bednarz, R. (2009). Effect of GIS learning on spatial thinking. *Journal of Geography in Higher Education, 33*(2), 183–198. https://doi.org/10.1080/03098260802276714

Margot, K. C., & Kettler, T. (2019). Teachers' perception of STEM integration and education: A systematic literature review. *International Journal of STEM Education, 6*, Article 2. https://doi.org/10.1186/s40594-018-0151-2

Markowitz, D. M., Laha, R., Perone, B. P., Pea, R. D., & Bailenson, J. N. (2018). Immersive virtual reality field trips facilitate learning about climate change. *Frontiers in Psychology, 9*, Article 2364. https://doi.org/10.3389/fpsyg.2018.02364

Martín-Páez, T., Aguilera, D., Perales-Palacios, F. J., & Vílchez-González, J. M. (2019). What are we talking about when we talk about STEM education? A review of literature. *Science Education, 103*(4), 799–822. https://doi.org/10.1002/sce.21522

Merritt, J., Lee, M. Y., Rillero, P., & Kinach, B. M. (2017). Problem-based learning in K–8 mathematics and science education: A literature review. *Interdisciplinary Journal of Problem-Based Learning, 11*(2), Article 3. https://doi.org/10.7771/1541-5015.1674

Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. *Teachers College Record, 108*(6), 1017–1054. https://doi.org/10.1111/j.1467-9620.2006.00684.x

Muhammad, I. (2025). SDGs learning using interactive web-based satellite imagery at SMAN 15 Semarang. *Journal of Geosciences and Environmental Studies, 2*(3), https://doi.org/10.53697/ijgaes.v2i3.4977

Nurcahyo, A. D., & Winanti, E. T. (2021). Pengaruh model problem based learning terintegrasi pendekatan induktif terhadap kemampuan berpikir spasial dan pengetahuan siswa pada materi mitigasi bencana. *Jurnal Pendidikan Geografi: Kajian, Teori, dan Praktek dalam Bidang Pendidikan dan Ilmu Geografi, 26*(1), 41–47. https://doi.org/10.17977/um017v26i12021p041

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., … Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ, 372*, Article n71. https://doi.org/10.1136/bmj.n71

Putra, N., Asrizal, A., & Usmeldi, U. (2023). Meta-analisis pengaruh STEM pada pembelajaran fisika terhadap pemahaman konsep dan keterampilan berpikir kreatif siswa. *INKUIRI: Jurnal Pendidikan IPA, 12*(3), 228–239. https://doi.org/10.20961/inkuiri.v12i3.79314

Salam, R. S., Nurfaika, N., Koem, S., & Rubama, F. (2023). Kemampuan berpikir spasial peserta didik menggunakan citra Google Earth pada mata pelajaran geografi di SMA Negeri 2 Gorontalo. *Geosfera: Jurnal Penelitian Geografi, 2*(2), 56–61. https://doi.org/10.37905/geojpg.v2i2.22569

Savery, J. R. (2006). Overview of problem-based learning: Definitions and distinctions. *Interdisciplinary Journal of Problem-Based Learning, 1*(1), 9–20. https://doi.org/10.7771/1541-5015.1002

Seminar, Y., Laiskhanov, S., Issakov, Y., & Gajić, T. (2026). A systematic review of geographical education of students through STEM. *Frontiers in Education, 11*, Article 1737076. https://doi.org/10.3389/feduc.2026.1737076

Strobel, J., & van Barneveld, A. (2009). When is PBL more effective? A meta-synthesis of meta-analyses comparing PBL to conventional classrooms. *Interdisciplinary Journal of Problem-Based Learning, 3*(1), 44–58. https://doi.org/10.7771/1541-5015.1046

Suasti, Y., & Aini, Z. M. (2025). Pengaruh penggunaan media “Google Earth” berbasis model pembelajaran problem based learning untuk meningkatkan berpikir spasial siswa pada mata pelajaran geografi di SMA N 5 Bukittinggi. *Pendas: Jurnal Ilmiah Pendidikan Dasar, 10*(2), 123–137. https://doi.org/10.23969/jp.v10i02.23918

Suasti, Y., & Shafira, M. I. (2025). Pengaruh penerapan media “Google Earth” berbasis model pembelajaran problem base learning untuk meningkatkan berfikir spasial siswa pada mata pelajaran geografi di SMA N 2 Pariaman. *Pendas: Jurnal Ilmiah Pendidikan Dasar, 10*(2), 211–222. https://doi.org/10.23969/jp.v10i02.23919

Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. *Cognitive Science, 12*(2), 257–285. https://doi.org/10.1207/s15516709cog1202_4

Thomas, J., & Harden, A. (2008). Methods for the thematic synthesis of qualitative research in systematic reviews. *BMC Medical Research Methodology, 8*, Article 45. https://doi.org/10.1186/1471-2288-8-45

Uttal, D. H., Meadow, N. G., Tipton, E., Hand, L. L., Alden, A. R., Warren, C., & Newcombe, N. S. (2013). The malleability of spatial skills: A meta-analysis of training studies. *Psychological Bulletin, 139*(2), 352–402. https://doi.org/10.1037/a0028446

Wai, J., Lubinski, D., & Benbow, C. P. (2009). Spatial ability for STEM domains: Aligning over 50 years of cumulative psychological knowledge solidifies its importance. *Journal of Educational Psychology, 101*(4), 817–835. https://doi.org/10.1037/a0016127