



Citarum River Microplastics: Development of an ESSI-Based Learning Material for Elementary Students' Scientific Literacy

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Abstrak

Pencemaran mikroplastik menimbulkan ancaman serius terhadap ekosistem dan kesehatan manusia, namun isu ini masih belum terintegrasi dalam kurikulum sains sekolah dasar. Penelitian ini mengembangkan dan memvalidasi bahan ajar sains kontekstual berbasis kerangka *Environmental Socio-Scientific Issues (ESSI)*, dengan menggunakan pencemaran mikroplastik di Sungai Citarum sebagai konteks nyata untuk mendukung literasi sains siswa sekolah dasar. Pengembangan dilakukan menggunakan model desain instruksional ADDIE melalui lima tahap iteratif, yaitu analisis, desain, pengembangan, implementasi, dan evaluasi. Validasi melibatkan tiga ahli materi (konten, media, dan bahasa), dua guru sekolah dasar, serta lima siswa kelas V yang dipilih secara purposif. Data dikumpulkan menggunakan lembar validasi ahli dan angket respons dengan skala Likert lima poin. Bahan ajar yang dihasilkan mengintegrasikan konten ilmiah, data lingkungan lokal yang autentik, serta aktivitas berbasis inkuiri melalui pendekatan narasi cerita dan infografis. Hasil validasi ahli menunjukkan skor rata-rata berkisar 4,54 hingga 4,77 pada dimensi konten, media, dan bahasa, seluruhnya dikategorikan "sangat layak". Guru menilai kepraktisan materi dengan sangat tinggi ($M = 4,63$), terutama pada aspek kontekstualisasi lokal, relevansi, dan kesesuaian bahasa, sementara siswa memberikan respons yang sangat positif ($M = 4,65$), khususnya dalam mengapresiasi relevansi materi dengan dunia nyata serta kontribusinya terhadap pengembangan literasi sains. Temuan ini menunjukkan bahwa bahan ajar yang dikembangkan dapat menjadi sumber belajar yang layak dan praktis untuk mengintegrasikan isu sosial-lingkungan lokal dalam pembelajaran sains sekolah dasar, serta berkontribusi terhadap pembelajaran literasi sains yang lebih kontekstual.

Kata Kunci: bahan ajar, isu sosiosaintifik lingkungan, literasi sains, mikroplastik,

Abstract

Microplastic pollution poses severe threats to ecosystems and human health, yet remains underrepresented in elementary school science curricula. This study developed and validated contextual science learning materials based on the *Environmental Socio-Scientific Issues (ESSI)* framework, using microplastic contamination in the Citarum River as a real-world case for elementary students' scientific literacy. The development employed the ADDIE instructional design model through five iterative stages: analysis, design, development, implementation, and evaluation. Validation involved three subject matter experts (content, media, and language), two elementary school teachers, and five purposively selected grade V students. Data were collected using expert validation sheets and response questionnaires with five-point Likert scales. The resulting material integrated scientific content, authentic local environmental data, and inquiry-based activities through narrative storytelling and infographics. Expert validation yielded mean scores ranging from 4.54 to 4.77 across the content, media, and language dimensions, all classified as "very feasible." Teachers rated the material's practicality highly ($M = 4.63$), particularly for its local contextualization, relevance, and language appropriateness, while students reported strongly positive perceptions ($M =$



4.65), particularly valuing the material's real-world relevance and its contribution to scientific literacy development. These findings demonstrate that the developed material provides a feasible and practical resource for integrating local socio-environmental issues into elementary science learning, contributing to more contextualized scientific literacy instruction.

Keywords: *environmental socio-scientific issue, learning material, microplastics, scientific literacy*

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Introduction

Microplastic pollution has emerged as one of the most pressing environmental challenges of the 21st century. These persistent pollutants now permeate all environmental compartments, from freshwater and marine ecosystems to soil and air, with their ability to adsorb hazardous chemicals and accumulate along food chains posing severe risks to both ecosystem integrity and human health (Chaudhary & Garg, 2024; Pal et al., 2024). Rivers serve as critical transport pathways for microplastics, carrying land-based pollution to marine environments. The Citarum River in West Java, Indonesia, exemplifies this crisis as one of the world's most polluted rivers (Hermana et al., 2024). Supporting over 5 million residents and numerous textile industries, the Citarum receives substantial untreated wastewater and plastic waste, with microplastics detected throughout its water, sediment, and biota, including fish consumed by local communities (Sembiring et al., 2020). This contamination pathway from river to dinner plate presents serious implications for human health, as microplastics disrupt biological processes in aquatic organisms, serve as vectors for toxic chemicals, and have been detected in seafood, drinking water, and human biological samples (Mamun et al., 2023; Yarahmadi et al., 2024).

Despite this environmental urgency, Indonesian primary education remains largely disconnected from students' lived environmental contexts. Science curricula emphasize abstract concepts while neglecting place-based learning approaches that could help students understand and respond to local environmental challenges (Sarbaini et al., 2022). To address this pedagogical gap, integrating Environmental Socio-Scientific Issues (ESSI) into science instruction has gained recognition as an effective approach. ESSI situates scientific

knowledge within real-world environmental, social, and ethical contexts, promoting critical thinking, scientific literacy, and civic responsibility (Hanson, 2022; Pérez-Martín & Esquivel-Martín, 2024). Studies demonstrate that ESSI-based instruction enhances students' ability to apply scientific concepts, engage in evidence-based decision-making, and develop environmental awareness (Collier et al., 2023). The urgency of equipping students with scientific literacy as the ability to interpret scientific phenomena, evaluate evidence, and make informed decisions on socio-environmental issues has never been greater (Heryani et al., 2024). The Citarum River microplastic crisis offers a highly relevant, place-based context for supporting such scientific literacy-oriented learning and engaging students with environmental challenges directly affecting their communities.

Conceptually, ESSI is grounded in three interconnected components: content, the scientific concepts underlying an environmental issue; process, the scientific and social reasoning skills required to evaluate the issue; and context, the socio-cultural setting in which the issue is embedded and experienced (Arifin et al., 2026; Sadler, 2011; Wati et al., 2026; Zeidler et al., 2009). This tripartite structure distinguishes ESSI from generic environmental education by requiring learners not only to acquire scientific content but also to engage in evidence-based reasoning about real, locally situated dilemmas. Scientific literacy, as conceptualized in the PISA framework, likewise comprises three interrelated competencies, explaining phenomena scientifically, evaluating and designing scientific inquiry, and interpreting data and evidence scientifically, which together enable individuals to engage as reflective citizens with science-related issues (OECD, 2019). Aligning ESSI's content-process-context structure with these

PISA competencies provides a coherent theoretical rationale for designing elementary learning materials that simultaneously build conceptual understanding and the reasoning skills necessary for informed civic participation (Hyunju Lee et al., 2024; Rahmanto et al., 2026).

Despite extensive research documenting microplastic contamination in aquatic systems (Hermana et al., 2024; Sembiring et al., 2020) and the growing application of ESSI pedagogy in secondary education (Vishal Kumar et al., 2024; Sanchez et al., 2024), research specifically addressing the development of ESSI-based learning materials for elementary learners remains relatively limited. First, existing microplastic education research has predominantly targeted secondary and higher education levels, although some studies have demonstrated the potential of microplastic-related learning activities for primary education (Raab & Bogner, 2020). However, systematic, curriculum-aligned learning materials specifically designed for young children remain relatively underexplored. Second, although the Citarum River's severe contamination is well-documented through environmental science research, this locally relevant environmental crisis has received limited attention as a basis for developing pedagogical resources that connect students' lived experiences with scientific learning. This disconnects limits opportunities for meaningful and contextualized scientific learning grounded in students lived experiences. Third, ESSI frameworks have demonstrated effectiveness for addressing complex environmental issues, but their systematic adaptation into developmentally appropriate elementary-level learning materials, particularly in locally situated environmental contexts, remains an area requiring further investigation. These gaps carry long-term consequences: robust evidence shows that early environmental education profoundly shapes lifelong environmental attitudes, behaviors, and civic engagement (Baierl & Bogner, 2021), yet Indonesian primary science curricula continue to prioritize decontextualized content over place-based, socially relevant learning experiences during these formative years (McKinnon, 2017).

Preliminary classroom observations and teacher interviews across five public elementary schools in Bandung further indicated the need for such learning materials. Across the observed schools, teachers reported limited familiarity

with the ESSI framework, while environmental topics were generally integrated incidentally rather than through dedicated curricular materials. Students showed enthusiasm toward environmentally themed questions but demonstrated limited engagement with scientific methods when discussing environmental problems.

To address these gaps, this study develops and validates contextual ESSI-based learning materials addressing Citarum River microplastic pollution for elementary students' scientific literacy. Employing the ADDIE (Analysis, Design, Development, Implementation, Evaluation) instructional design model, which provides a systematic framework for developing contextually grounded educational resources, this study addresses three research questions.

1. What are the design characteristics of the ESSI-based learning material addressing microplastic pollution in the Citarum River for elementary students' scientific literacy?
2. How feasible is the developed learning material based on expert evaluation across content, media, and language dimensions?
3. How do teachers and students perceive the practicality and usability of the material following limited try-out implementation?

The novelty of this study lies in the development and validation of a place-based ESSI learning material that integrates the locally relevant issue of Citarum River microplastic pollution with scientific literacy-oriented learning for elementary students. By bridging environmental science research and elementary pedagogy, this study offers validated, place-based instructional resources that can support the integration of local socio-environmental issues into elementary science learning.

Method

This research employed a Research & Development (R&D) methodology to systematically develop and validate a contextual learning resource that integrates a locally relevant environmental socio-scientific issue with scientific literacy dimensions. The study utilized the ADDIE (Analysis, Design, Development, Implementation, Evaluation) instructional design model, which provides a systematic, iterative framework for developing effective educational materials (Aldoobie, 2015; Branch, 2009). ADDIE was selected over alternative models due to its emphasis on continuous feedback and refinement, making it

well-suited for developing materials for novel contexts such as elementary-level ESSI instruction (Almelhi, 2021). The study focused on the development and validation of the learning material; the implementation stage was conducted as a limited try-out to examine its feasibility, practicality, and usability rather than to measure changes in students' scientific literacy.

The development process systematically followed the five stages of the ADDIE model (Branch, 2009), with iterative refinement based on stakeholder feedback at each stage. The process began with the analysis stage, in which a needs analysis was conducted to identify curricular gaps, environmental context, and student needs, informing subsequent decisions about content scope and instructional approach.

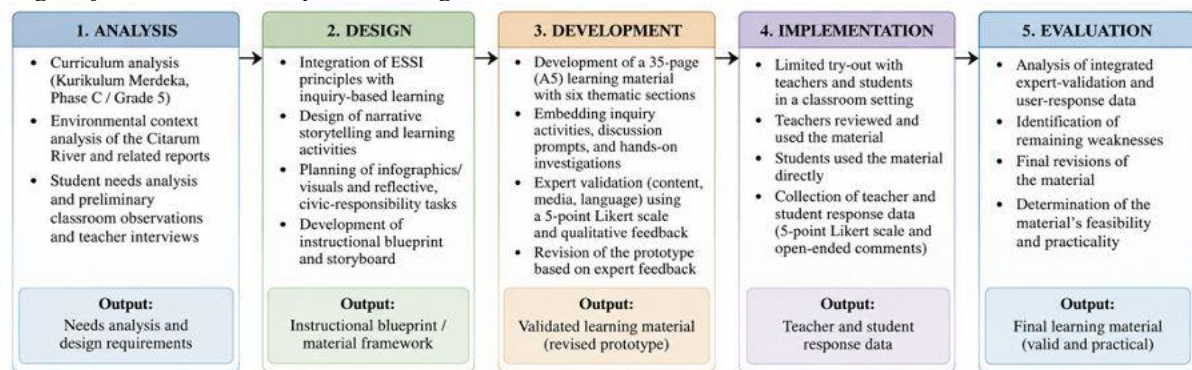
As part of the preliminary needs analysis, classroom observations and teacher interviews were conducted across five public elementary schools in Bandung. The observations and interviews focused on teachers' familiarity with the ESSI framework, how environmental topics were integrated into science learning, and students' engagement with scientific methods when discussing environmental problems. The preliminary findings indicated limited teacher

familiarity with ESSI, incidental rather than systematic integration of environmental topics, and limited student engagement with scientific methods. These findings were used to inform the content scope and instructional approach of the learning material.

This was followed by the design stage, in which an instructional blueprint was developed by integrating ESSI principles with inquiry-based learning, narrative storytelling, supporting infographics, and reflective, civic-responsibility tasks. In the development stage, the prototype learning material was produced according to the design blueprint and then evaluated through expert validation covering content, media, and language dimensions, before being revised based on expert feedback. The revised material then entered the implementation stage, in which it was trialed on a limited basis with teachers and students to gather responses regarding its practicality and usability. Finally, in the evaluation stage, the expert-validation and user-response data were analyzed to identify remaining weaknesses, followed by final revisions and a determination of the material's feasibility and practicality. Each stage is elaborated in Figure 1.

Figure 1.

Stages of Material Development Using the ADDIE Model



Three distinct participant groups were selected through purposive sampling. First, three subject matter experts participated in content validation: a language specialist, a media design expert, and a science content specialist. Experts were selected based on their documented expertise in relevant domains and willingness to provide detailed formative feedback. Second, two Grade V teachers with a minimum of five years of teaching experience. Third, five grade V students from a public elementary school in West Java Province, Indonesia, were

purposely selected to take part in the limited implementation trial.

The selection of a public elementary school in West Java was intended to align the try-out context with the geographical and cultural setting of the Citarum River case itself, ensuring that participating teachers and students shared direct familiarity with the environmental issue addressed in the material. Grade V was selected because students at this level have generally developed the reading proficiency and abstract reasoning necessary to engage with

narrative and infographic content, while remaining within the upper elementary band targeted by the material's curricular alignment.

Instruments used included expert validation sheets, comprising three instruments for content, media, and language validation, which were used to obtain quantitative ratings and qualitative feedback from the three experts, while teacher and student response questionnaires were used to obtain practicality and usability responses from the two teachers and five students during the implementation trial. Both types of instruments used a five-point Likert scale accompanied by open-ended items for qualitative comments, critiques, and suggestions for improvement. Quantitative data from the expert validation sheets and response questionnaires were analyzed using descriptive statistics, with mean scores (M) calculated for each assessment dimension and overall. Material feasibility was determined using the criteria adapted from Akbar (2013), as summarized in Table 1.

Prior to use, each validation and response instrument was developed based on a blueprint outlining the dimensions and indicators to be assessed for each validator group, which was reviewed for content coverage before being finalized into the five-point Likert format. Mean scores for each indicator and dimension were computed by averaging respondents' ratings within that group, and overall category scores were then compared against the feasibility ranges in Table 1 to determine the classification for each dimension and for the material as a whole.

Table 1.
Feasibility Criteria

Score Range	Classification
$X > 4.20$	Very Feasible
$3.41 < X \leq 4.20$	Feasible
$2.60 < X \leq 3.41$	Moderately Feasible
$1.80 < X \leq 2.60$	Less Feasible
$X \leq 1.80$	Not Feasible

Materials achieving a "Feasible" or "Very Feasible" rating were considered acceptable for implementation. Qualitative data, consisting of critiques, suggestions for improvement, and responses from experts, teachers, and students, were analyzed using the interactive model proposed by Miles, Huberman, and Saldaña (2014), involving data condensation, data display, and conclusion drawing and verification.

Result and Discussion

Design of the contextual ESSI-based learning material

The Analysis stage provided the basis for the subsequent design of the learning material. Curriculum review demonstrated that while scientific literacy competencies are embedded in national standards, implementation remains disconnected from students lived environmental contexts. The preliminary classroom observations and teacher interviews conducted across five public elementary schools in Bandung further indicated limited familiarity with the ESSI framework among teachers and an incidental rather than systematic integration of environmental topics into science learning. Students showed interest in environmental questions but demonstrated limited engagement with scientific methods when discussing environmental problems. These findings informed the decision to develop a structured, place-based learning material that could provide teachers with a ready-to-use ESSI learning resource while offering students more explicit opportunities to connect environmental problems with scientific concepts and inquiry.

In the Design stage, these needs were translated into an instructional blueprint that integrated ESSI principles with inquiry-based learning, narrative storytelling, supporting infographics, and reflective civic-responsibility tasks. The resulting 35-page learning material, *"Tracing Microplastics from Citarum River to the Dinner Plate,"* integrates six key characteristics. First, it employs narrative storytelling to trace microplastic pathways from local rivers through food chains to human consumption, making abstract scientific concepts tangible through familiar contexts. This narrative approach reflects sociocultural learning theory suggesting that contextualized stories enhance comprehension and retention among young learners (Egan, 2005; Heryani et al., 2024). Second, the material incorporates authentic local data from Citarum River contamination studies, providing scientific rigor while maintaining personal relevance for students whose communities are directly affected (Kjelvik & Schultheis, 2019). Third, inquiry-based activities promote active investigation rather than passive information reception. Fourth, infographics and visual representations employ dual-coding principles to

support diverse learning preferences and reduce cognitive load (Dogomeo & Aliasas, 2022; Mayer & Moreno, 2014). Fifth, reflective tasks prompt students to evaluate evidence and consider ethical dimensions of environmental decisions, thereby creating opportunities for scientific literacy-oriented reasoning (Khazen et

al., 2025; Sadler, 2004). Sixth, explicit connections between scientific concepts and social responsibility encourage civic engagement beyond classroom learning. The sample display of the developed learning material is shown in Figures 2–5.

Figure 2.

Cover Design and Introduction Page of the Learning Material



Figure 3.

Example of an Infographic and Inquiry Activity Page



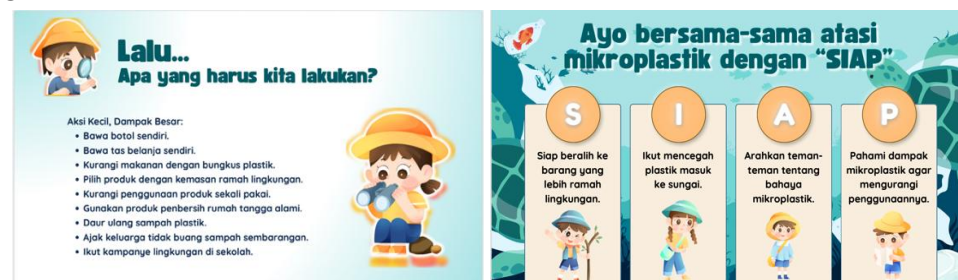
Figure 4.

ESSI Integration in Learning Material



Figure 5.

Suggested Environmental Actions



These characteristics collectively address a significant pedagogical gap. While previous ESSI materials have targeted secondary education (Pessoa et al., 2025; Sadler, 2011; Zeidler et al., 2009), this represents systematic adaptation for elementary learners through developmentally appropriate scaffolding, visual support, and simplified language. Unlike awareness campaigns lacking curriculum integration, these materials align explicitly with national science standards while extending content to address emerging environmental challenges absent from textbooks.

Feasibility of the learning material based on expert validation

In the Development stage, the instructional blueprint was transformed into a prototype learning material and subsequently reviewed by content, media, and language experts. Expert feedback was used to refine the prototype, particularly in terms of visual quality, case-study depth, terminology support, and scaffolding for scientific literacy development.

Expert validation across three dimensions yielded consistently high ratings (Table 2), with all overall mean scores exceeding 4.20, classified as "Very Feasible" using the criteria established in Table 1 (Akbar, 2013). Content experts rated scientific accuracy highest ($M = 4.67$), appreciating factual precision regarding microplastic sources, pathways, and impacts, alongside effective integration of Citarum River data. This strong rating validates the material's scientific credibility, addressing concerns that elementary materials sometimes oversimplify to the point of inaccuracy (Duschl et al., 2007; Fakhriyah et al., 2025). Media experts rated visual quality and accessibility highly ($M = 4.54$), noting that infographics effectively communicated complex processes and that dual-format availability (print and digital) enhanced accessibility. Language experts provided the highest overall rating ($M = 4.77$), confirming age-appropriate vocabulary, grammatical accuracy, and engaging communicative style. The resulting Expert Validation Results, based on the assessments from these three expert groups, are presented in detail in Table 2.

Table 2.
Expert Validation Results

Validators	Aspects	Average Score (M)	Category	Key Strength	Suggested Improvement
Media Expert	Visual Display	4.50	Very Feasible	Visual clarity; dual-format access	Higher resolution for select images
	Image Quality	4.33	Very Feasible		
	Typography and Readability	4.67	Very Feasible		
	Accessibility	4.67	Very Feasible		
	Overall	4.54	Very Feasible		
Content Expert	Content Alignment with Scientific Concepts	4.67	Very Feasible	Scientific rigor; local data integration	Enhanced case study depth
	Relevance to Environmental Socio-Scientific Issues (ESSI)	4.33	Very Feasible		
	Contribution to Scientific Literacy Development	4.67	Very Feasible		
	Suitability for Elementary Students' Developmental Level	4.67	Very Feasible		
	Completeness and Coherence of the Material	5.00	Very Feasible		
	Overall	4.67	Very Feasible		
Language Expert	Language Accuracy	5.00	Very Feasible	Age-appropriate; engaging tone	Glossary for technical terms
	Clarity and Comprehensibility	4.67	Very Feasible		
	Terminology Accuracy	4.50	Very Feasible		
	Suitability with Elementary Students' Developmental Level	4.67	Very Feasible		

	Language Engagement	5.00	Very Feasible		
	Overall	4.77	Very Feasible		

These validation scores exceed those reported for comparable ESSI-based materials in recent studies. For instance, Kumar et al. (2024) reported expert validation scores of $M = 4.3$ for climate change materials at secondary level, while Sadler et al. (2017) obtained $M = 4.1$ for water quality modules. The higher ratings in this study likely reflect the explicit focus on local relevance. Experts noted that Citarum River integration created compelling "teachable moments" unavailable in generic environmental curricula. This finding supports place-based education theory suggesting that geographic and cultural proximity enhances both pedagogical effectiveness and stakeholder buy-in (Mannion et al., 2013; Sobel, 2004), consistent with more recent evidence linking place-based environmental programs to measurable gains in students' environmental literacy and stewardship (Hamilton & Marckini-Polk, 2023).

Qualitative feedback revealed important nuances beyond quantitative ratings. Experts emphasized that the material successfully balanced scientific accuracy with accessibility, avoiding both oversimplification and excessive technicality. One content expert noted that the material demonstrated how complex environmental issues can be made comprehensible for young learners without sacrificing scientific integrity. However, experts recommended enhanced explicit instruction for critical thinking activities, suggesting that while the material prompted analysis, more structured guidance would help teachers facilitate higher-order thinking. This feedback aligns with research indicating that inquiry-based learning requires careful scaffolding, particularly for elementary students and novice teachers (Furtak et al., 2012; Hmelo-Silver et al., 2007), a pattern reaffirmed by more recent meta-analytic evidence showing consistent positive effects of scaffolded inquiry-based instruction on students' higher-order thinking skills (Antonio & Prudente, 2024).

Teachers' and students' perceptions of practicality and usability

Teacher responses

During the Implementation stage, two elementary teachers rated material feasibility highly across nine indicators (Table 3), with an overall mean of $M = 4.63$. Highest ratings appeared for local contextualization ($M = 4.81$), content relevance ($M = 4.81$), and language appropriateness ($M = 4.81$), suggesting strong appreciation for materials addressing tangible community issues in accessible language. These findings resonate with research demonstrating that teachers value curriculum materials directly applicable to their students' lives and requiring minimal adaptation (Ke et al., 2021; Özüdoğru & Sakallıoğlu, 2026).

Comparatively lower ratings for student engagement ($M = 4.31$) and literacy support ($M = 4.38$), though still in the "Very Feasible" range, indicate areas for refinement. Teachers suggested incorporating more hands-on investigations and collaborative activities to sustain attention. This feedback parallels findings by Boyliyeva (2024) and Bybee (2015) that elementary students particularly benefit from kinesthetic learning and peer interaction when engaging with abstract concepts. The moderate literacy support rating suggests that while materials promoted scientific literacy generally, explicit strategies for reading comprehension, vocabulary development, and argumentation could be strengthened, a recommendation consistent with research on literacy integration in science instruction (Cervetti et al., 2006; Pearson et al., 2010), further substantiated by a recent meta-analysis showing significant positive effects of integrated literacy-content instruction on both vocabulary and comprehension outcomes among elementary students (Hwang et al., 2021).

Table 3.*Teacher Feasibility Assessment*

Indicators	Average Score (M)	Interpretation
Local Contextualization	4.81	Highly valued community relevance
Content Relevance	4.81	Strong curriculum alignment
Language Appropriateness	4.81	Age-appropriate communication
Implementation Feasibility	4.69	Practical for classroom use
Scientific Accuracy	4.63	Credible information source
Visual Support	4.63	Effective learning aids
Clarity of Instructions	4.56	Adequate teacher guidance
Literacy Support	4.38	Moderate literacy integration
Student Engagement	4.31	Adequate but improvable
Overall	4.63	Very Feasible

The teacher response questionnaire revealed implementation considerations beyond feasibility ratings. Several teachers noted that while the material was comprehensive and potentially challenging given time constraints. They recommended identifying "core" versus "optional" activities to provide flexibility. Additionally, teachers requested supplementary resources such as assessment rubrics and discussion prompts to support facilitation of socio-scientific discussions, a need identified in broader ESSi literature where teachers often feel underprepared to navigate controversial topics (Klemenčič et al., 2023; H Lee et al., 2013; Sadler et al., 2006). These insights, while indicating areas for enhancement, ultimately suggest that the material addresses a genuine curricular need and that teachers are eager to implement it with appropriate support.

Student responses

Student questionnaire results demonstrated highly positive perceptions across all indicators ($M = 4.65$), addressing the third research question. Most notably, students reported enhanced environmental awareness ($M = 4.90$), increased sense of responsibility to reduce plastic waste ($M = 4.60$), and appreciation for real-world examples making the topic tangible ($M = 4.80$). These affective outcomes are particularly significant given research demonstrating that elementary years are formative for environmental attitudes and that early positive experiences with environmental issues predict long-term pro-environmental behavior (Collado et al., 2015; Evans et al., 2018).

Table 4.*Student Perceptions of Learning Material Quality*

Dimension	Indicators	Average Score (M)	Interpretation
Cognitive Outcomes	Conceptual understanding	4.70	Strong comprehension
	Process understanding	4.50	Good clarity
	Contextual connection	4.80	Highly relatable
Pedagogical Quality	Visual support	4.60	Effective aids
	Activity engagement	4.40	Adequately engaging
	Scientific Literacy	4.70	Promotes analysis
	Language accessibility	4.80	Age-appropriate
	Overall enjoyment	4.50	Positive experience
Affective Outcomes	Awareness development	4.90	Highest impact
	Behavioral intention	4.60	Strong motivation
Overall		4.65	Very Feasible

The scientific literacy indicator received a positive mean score of 4.70, reflecting students' favorable perceptions of the material's support for scientific literacy. This positive perception is consistent with research emphasizing the potential of socio-scientific issues to contextualize science learning and engage students with real-world environmental problems (Sadler & Zeidler, 2005). The high rating for visual support ($M = 4.60$) indicates that students perceived the multimedia elements as helpful for understanding complex information, consistent with the cognitive theory of multimedia learning (Mayer & Moreno, 2014). Relatively lower ratings for activity interest ($M = 4.40$) and general enjoyment ($M = 4.50$), though still positive, mirror teacher feedback suggesting room for more interactive elements. This pattern, characterized by positive cognitive and affective perceptions alongside moderate engagement, resembles findings in elementary inquiry instruction more broadly, where conceptual learning may occur even when activities are not maximally entertaining (Furtak et al., 2012). However, research on sustained environmental education suggests that enjoyment and engagement predict continued interest in environmental topics (Ardoin & Bowers, 2020), indicating that enhancing interactive elements could yield long-term benefits beyond immediate learning outcomes.

Taken together, the Implementation and Evaluation stages indicate that teachers and students perceived the material as practical, relevant, and accessible, while also identifying specific areas for further refinement. The convergence of teacher and student responses particularly supports the value of local contextualization and age-appropriate presentation. At the same time, the limited implementation with two teachers and five students from one school means that these findings should be interpreted as context-specific evidence of practicality and usability rather than evidence of general effectiveness or scalability. During the Evaluation stage, the teacher and student responses were reviewed to identify remaining areas for refinement, particularly student engagement, literacy support, and flexibility of classroom activities.

Limitations of the Study

Several limitations should be acknowledged. First, the implementation trial involved a small, purposively selected sample of two teachers and five students from a single elementary school, which limits the generalizability of the feasibility and practicality findings to broader elementary populations and other regional contexts. Second, the try-out was limited in scope and duration, focusing on validators' perceptions of the material rather than on measured pre- and post-intervention gains in students' scientific literacy, meaning that claims regarding learning impact remain inferential rather than directly demonstrated. Third, the study relied primarily on self-reported Likert-scale and qualitative responses, which are susceptible to social desirability bias, particularly among young student respondents. Future research employing larger, more diverse samples, quasi-experimental designs with pre-post literacy measures, and longer implementation periods would help substantiate the material's effectiveness beyond its demonstrated feasibility and practicality.

Conclusion

This study developed and validated a contextual, ESSi-based learning material addressing microplastic pollution in the Citarum River to enhance elementary students' scientific literacy, employing the ADDIE instructional design model through five iterative stages. Three main findings emerged in response to the study's research questions. First, the resulting 35-page material integrated six key characteristics: narrative storytelling, authentic local environmental data, inquiry-based activities, dual-coded visual representations, reflective scientific literacy tasks, and explicit civic-engagement connections representing a systematic adaptation of ESSi principles, previously concentrated at the secondary level, for elementary learners. Second, expert validation across the content, media, and language dimensions yielded consistently high ratings ($M = 4.54 - 4.77$), all classified as "Very Feasible," confirming that the material successfully balanced scientific accuracy with age-appropriate accessibility. Third, the limited implementation trial demonstrated strong practicality and usability from both teachers ($M = 4.63$) and students ($M = 4.65$), with

particularly high appreciation for the material's local relevance, language appropriateness, and contribution to students' environmental awareness and scientific literacy, alongside moderate ratings for student engagement and literacy support that point to specific areas for refinement.

These findings carry both practical and theoretical implications. Practically, the developed material offers science teachers and curriculum developers a ready-to-use, validated resource for integrating local socio-environmental issues into elementary science instruction, while the underlying ADDIE-based design process provides a structured example that may be adapted to other locally relevant environmental issues beyond microplastic pollution, such as deforestation, air pollution, or renewable energy, depending on the ecological context of a given region. Theoretically, this study contributes to the ESSI literature by demonstrating that a framework previously concentrated at the secondary level can be systematically and effectively adapted for elementary learners when supported by developmentally appropriate scaffolding, narrative structure, and visual representation. It further extends place-based education theory by empirically evidencing that geographic and cultural proximity to an environmental issue enhances both expert-rated feasibility and end-user practicality, offering a concrete, validated case to a body of literature that has, until now, been largely conceptual or secondary-level in focus. Collectively, these findings provide a context-specific example of how ESSI can be adapted into an elementary science learning material in an environmentally affected school context. Further studies involving larger and more diverse samples are needed to examine whether this approach can be transferred to other contexts and whether it improves students' scientific literacy.

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