

Research Article

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EXARIS Model Development: Enhancing Elementary Scientific and Digital Literacy

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Abstract

Background/purpose. Study addresses the problem of low scientific and digital literacy among Grade 6 students (Phase C) in the IPAS (Science and Social Studies) subject under the Merdeka Curriculum, particularly in the theme “Our Endangered Earth.” The main purpose of the study is to develop and evaluate the EXARIS learning model (Exploration, Analysis, Reflection, Integration, Sharing) as an innovative solution that enhances both scientific and digital literacy, aligned with 21st-century learning demands and curriculum goals.

Materials/methods. The EXARIS model was developed using a systematic instructional design approach based on the ADDIE framework (Analysis, Design, Development, Implementation, and Evaluation). Validation was conducted through expert review, while practicality was assessed by classroom teachers. The model's effectiveness was measured using a quasi-experimental design with a Paired Samples T-Test dan Anacova One Way.

Results. The expert validation showed a high level of validity (average score = 3.85 on a 4-point scale). Practicality testing indicated that teachers found the model easy to implement (average score = 3.70). Effectiveness testing revealed significant improvements in students' digital literacy (Mean Difference = 1.79, $p < 0.001$) and scientific literacy (Mean Difference = 1.65, $p < 0.05$).

Conclusion. The EXARIS learning model is valid, practical, and effective for improving scientific and digital literacy among Grade 6 students in the IPAS subject within the Merdeka Curriculum. This model offers an innovative pedagogical strategy to strengthen students' foundational competencies and meet the needs of 21st-century education.

1. Introduction

Scientific and digital literacy are two key competencies in 21st-century education, essential for learners to master early. Scientific literacy encompasses understanding scientific concepts, applying them in daily life, and employing critical, systematic thinking to solve problems. Digital literacy involves effectively and responsibly accessing, understanding, evaluating, and utilizing information through digital media (Ng, 2012). Both form the foundation for preparing individuals to address complex global challenges. Ideally, elementary education should instill strong fundamentals in scientific and digital literacy, enabling students to master content while understanding scientific thinking processes and digital ethics (El Messaoudi, M., 2024). Kurikulum Merdeka” (Independent Curriculum), a national curriculum framework that emphasizes student-centered learning, flexibility in content selection, project-based learning, and the development of essential competencies to meet the challenges of the 21st century in Indonesia. By integrating the principles of the Kurikulum Merdeka, the analysis ensured that the EXARIS model would be relevant, adaptive, and aligned with current national education policy. The Merdeka Curriculum explicitly emphasizes developing scientific literacy, critical thinking, and digital technology integration in Science and Social Studies (IPAS) Phase C (Kemendikbudristek, 2022). However, these goals have not been uniformly achieved across all elementary institutions (Septiana, 2025).

International studies reveal that Indonesian students’ scientific literacy remains low. According to the 2018 Programme for International Student Assessment (PISA), Indonesia's scientific literacy score was 396, significantly below the OECD average of 489 (OECD, 2019), indicating most students lack basic proficiency in understanding and applying scientific concepts in real-life contexts (<https://www.oecd.org/en/countries/indonesia.html>). This highlights major challenges in science education, particularly at the elementary level. Low scientific literacy is further reflected in limited inquiry-based learning experiences and insufficient contextual approaches in IPAS instruction. Research shows that elementary science education remains dominated by expository methods, where teachers explain concepts without active student exploration (Firman, 2020), hindering the development of scientific thinking and essential process skills.

Meanwhile, digital literacy has yet to become a primary focus in elementary education, despite children living in dynamic digital ecosystems (Musa S, 2025). A 2022 survey by Indonesia's Ministry of Communication and Informatics (Kominfo) found only 30% of elementary students demonstrated basic understanding of ethical and productive technology use (Kominfo, 2022), indicating a gap between technology exposure and meaningful learning application. Low digital literacy also stems from insufficient daily technology integration. Many elementary teachers remain unaccustomed to optimally using digital media (Rohendi & Djudin, 2021), which exacerbates the issue since children often use technology for entertainment rather than knowledge exploration or scientific communication. When properly guided, digital tools can effectively strengthen scientific literacy. Developing a learning model integrating scientific communication and digital technology is crucial. The EXARIS model (Exploration, Analysis, Reflection, Integration, Sharing) offers a solution, providing active, reflective, and contextual learning experiences that emphasize scientific thinking and digital technology for communication and collaboration (Rachmadtullah et al., 2023). The EXARIS learning model synthesizes Inquiry-Based Learning (IBL) and Experiential Learning (EL). Inquiry-Based Learning (IBL) emphasizes scientific exploration, questioning, and investigation as the foundation for constructing knowledge, while Experiential Learning (EL) provides direct, meaningful experiences in real-world contexts that support reflection and application (Hmelo-Silver et al., 2007; Kolb, 2015). By integrating these two approaches, EXARIS encourages students to engage actively in experiencing, analyzing, reflecting, integrating, and sharing knowledge, thereby fostering both scientific literacy and digital literacy in a coherent learning process (Fitria, 2023).

The novelty of EXARIS lies in its "Integration" phase, which emphasizes connecting prior knowledge with new concepts and applying them to real-life contexts (Bransford et al., 2000). This phase addresses the simultaneous enhancement of scientific and digital literacy, both requiring skills to integrate information from diverse sources and formats. The "Integration" syntax reflects authentic constructivist learning, where students actively construct understanding through association, analysis, and application (Jonassen, 1999), aligning with 21st-century demands for integrating content, skills, and technology.

This research develops a scientific communication-based EXARIS model for Phase C IPAS to enhance elementary students' scientific and digital literacy. IPAS, as a transdisciplinary subject, integrates natural sciences, social sciences, and technology in real-world contexts (Kemendikbudristek, 2022), making it ideal for balanced literacy development. The model aims to activate critical thinking, exploratory abilities, and productive digital technology use while addressing cognitive, affective, and psychomotor domains (Anderson & Krathwohl, 2001), fostering reflective and digitally responsible learners.

2. Literature Review

Chen's (2021) Inquiry-Based Learning (IBL) model emphasizes four systematic steps: formulating questions based on IPAS phenomena (Question Formulation), gathering data through experiments or digital sources (Evidence Gathering), constructing scientific arguments (Explanation Construction), and presenting findings using technology (Communication). While effective for developing scientific literacy through independent investigation, it often limits structured scientific communication (Smith et al., 2020). To enrich learning, IBL can be integrated with Kolb's (1984) Experiential Learning (EL) cycle: direct interaction with scientific phenomena (Concrete Experience), critical analysis of experiences (Reflective Observation), theoretical modeling (Abstract Conceptualization), and concept application in new contexts (Active Experimentation). Though EL transforms empirical experiences into abstract knowledge, it underemphasizes digital product creation as a literacy expression (Fraillon et al., 2019). The EXARIS model emerges as an innovative synthesis of IBL, EL, and scientific communication (Kim et al., 2022). Its Explorer phase adopts Question Formulation (IBL) and Concrete Experience (EL) through digital simulation-assisted exploration. The Analysis phase integrates Evidence Gathering (IBL) and Reflective Observation (EL) for scientific data processing. The Reflection phase deepens Abstract Conceptualization (EL) through argumentative discussions on platforms like Flipgrid. EXARIS's novelty lies in its Integration phase, enabling digital product creation (e.g., infographics), and the Share phase, involving scientific content dissemination to the public. These phases address IBL and EL's limitations in digital literacy and collaboration (Kim et al., 2022).

Figure 1. EXARIS Learning Model.

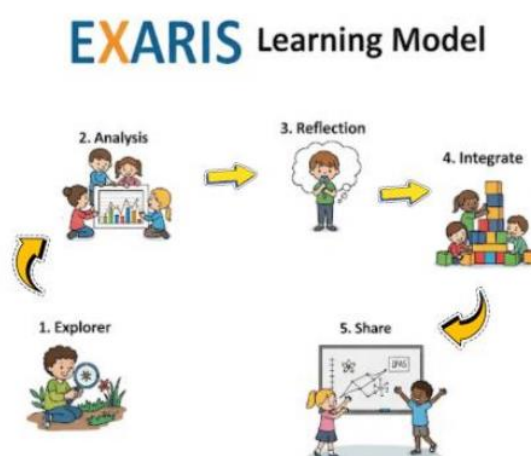


Figure 1. EXARIS Learning Model.

The EXARIS learning model was developed through a discovery process that extracted the strengths of Inquiry-Based Learning (IBL) and Experiential Learning (EL). While IBL emphasizes scientific exploration, investigation, and evidence-based reasoning, EL highlights direct experience, reflection, and real-world application. The synthesis of these approaches resulted in the EXARIS framework, which consists of the stages of exploration, analysis, reflection, integration, and sharing. The flow of this developmental process is illustrated in Figure 2.

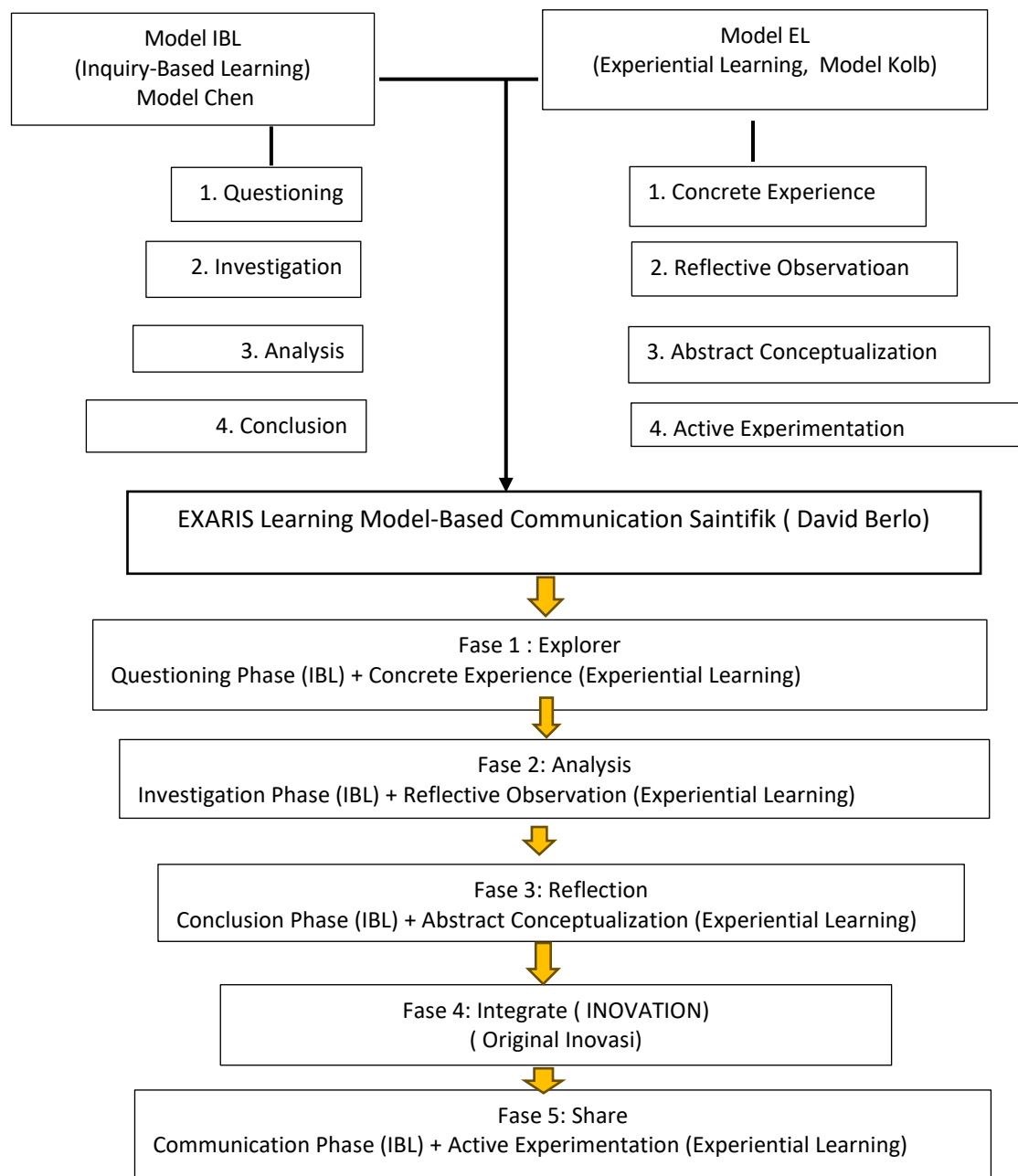


Figure 2. The Extraction Process of the EXARIS Learning Model Based on Scientific Communication

3. Methodology

This study employed a Research and Development (R&D) methodology, guided by the ADDIE model (Analysis, Design, Development, Implementation, and Evaluation) to develop and validate the EXARIS learning model. The ADDIE framework was selected due to its systematic nature and wide acceptance in educational innovation research. Further details can be seen in Figure 3.

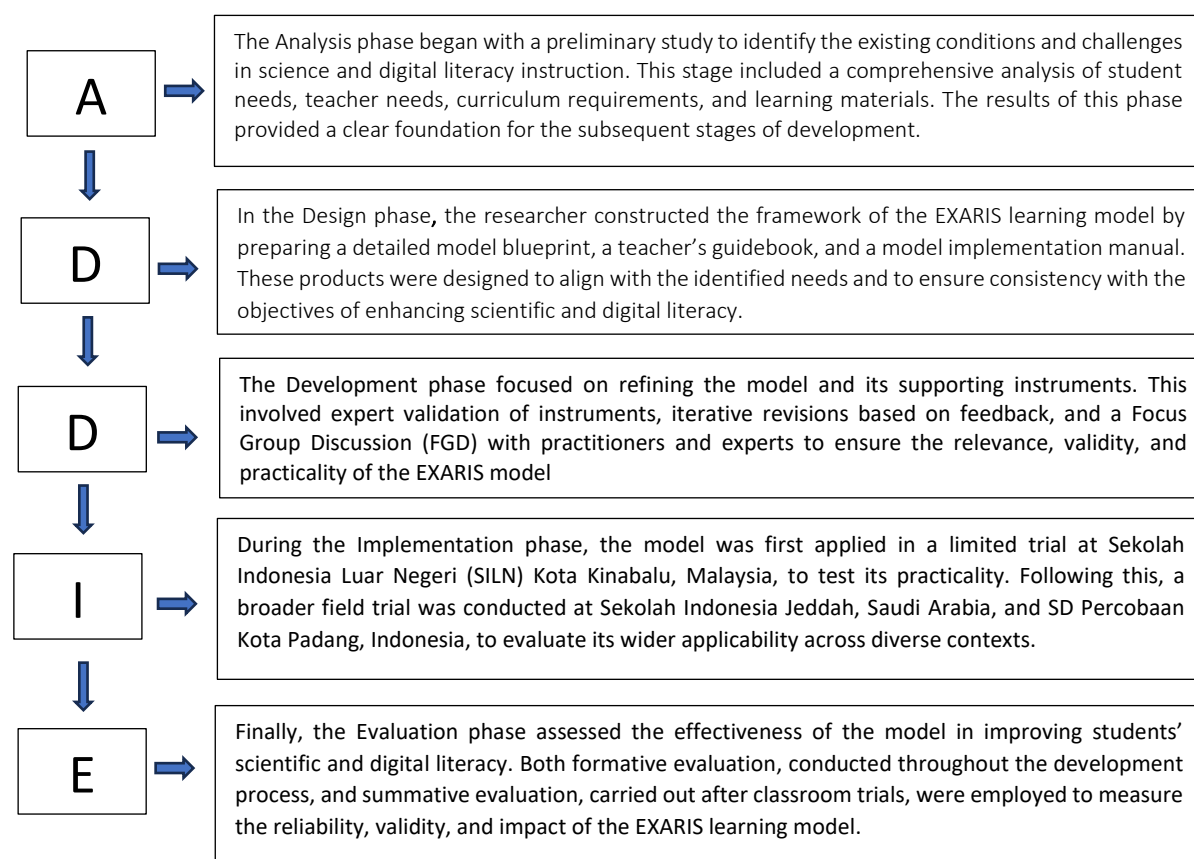


Figure 3. Illustrates the Phases of the ADDIE Model Applied in this Study.

3.1. Research Design

The research was designed in two main stages: (1) development of the EXARIS learning model through iterative design and expert validation, and (2) limited-scale experimental testing to evaluate its practicality and effectiveness. The study was conducted across three educational institutions: Sekolah Indonesia Luar Negeri (SILN) Kota Kinabalu (Malaysia), SILN Jeddah (Saudi Arabia), and SD Percobaan Kota Padang (Indonesia). The selection of these three schools was based on the diversity of their educational contexts and student characteristics, which provide a comprehensive foundation for developing and testing the EXARIS model. SILN Kota Kinabalu (Malaysia) and SILN Jeddah (Saudi Arabia) represent Indonesian schools abroad that face unique challenges in preserving national identity, fostering civic literacy, and enhancing digital engagement in multicultural settings. Meanwhile, SD Percobaan Kota Padang (Indonesia) represents schools within the national education system, enabling comparison with domestic learning conditions. This combination ensures that the EXARIS model is examined across both international and local contexts, thereby strengthening its validity, adaptability, and broader relevance.

3.2. Participants

A limited-scale trial was carried out in two purposively selected classes, comprising an experimental group (28 students) and a control group (30 students). Both groups were matched in terms of initial competency levels and exposure to a similar curriculum to ensure comparability.

3.3. Data Collection Procedures and Instruments

Data were collected using multiple instruments to ensure triangulation and rigor: Observation sheets were employed to monitor the implementation fidelity of the EXARIS model during classroom activities. Semi-structured interviews were conducted with teachers and students to gain in-depth

perspectives on the model's practicality and engagement. Expert validation questionnaires were used to evaluate the content validity, construct validity, and relevance of the developed model. Pre- and post-tests on scientific literacy and digital literacy were administered to measure students' learning gains. The test items were developed based on PISA and national curriculum indicators and validated through expert review and pilot testing.

3.4. Analytical Techniques

A mixed-methods approach was applied, integrating qualitative and quantitative analyses. Qualitative data from observations and interviews were analyzed descriptively and thematically to identify strengths, weaknesses, and contextual challenges of the model's implementation. Quantitative data were processed using SPSS v.25. Practicality was assessed through descriptive statistics (mean scores and percentage agreements) derived from teacher/student responses and observation ratings.

3.5. Effectiveness was Tested Through Inferential Statistics

Normality tests (Kolmogorov-Smirnov) and homogeneity tests (Levene's Test) were conducted as pre-requisites. Paired Sample T-Tests were used to compare pre- and post-test scores within each group. Independent Sample T-Tests compared the experimental and control groups' performance, providing evidence of the EXARIS model's impact on 21st-century literacy skills.

4. Results

4.1. Analysis Phase

Curriculum Analysis: The Merdeka Curriculum In Indonesia (Permendikbudristek No. 262/2024) emphasizes inquiry-based and differentiated learning, prioritizing scientific and digital literacy in IPAS Phase C (Grades 4-6). However, implementation challenges persist; a Kemdikbudristek (2022) study found 68% of IPAS material is taught theoretically without scientific or technological integration, failing OECD digital-scientific literacy standards. This is exacerbated by a lack of operational guidance for inquiry-based, technology-integrated teaching (Sutimah et al., 2024), highlighting an urgent need for a congruent learning model.

Student Needs Analysis: A preliminary study (July-Dec 2024) with 120 IPAS Phase C students in Kota Kinabalu revealed significant gaps: passive learning dominated (85% lecture, 72% conventional Q&A) with minimal exploration or digital tool use. Scientific literacy was low (only 15% could analyze cause-and-effect; 70% struggled with real-life application). Digital literacy was limited to content consumption (92% for entertainment, 18% for science-based digital creation) (Kota Kinabalu Indonesian School Preliminary Study Report, 2024; Guru Inovatif, 2024). This aligns with OECD (2023) findings that Indonesian students (10-12 years) have the lowest digital literacy scores in Southeast Asia, particularly in information evaluation and digital content creation. Students expressed a need for hands-on experiments (88%), interactive technology (79%), and project-based collaboration (91%). **Teacher Needs Analysis:** Interviews with 5 IPAS teachers in Kota Kinabalu identified three critical competency gaps: partial understanding of scientific literacy (76% defined it as textbook mastery, not scientific thinking), superficial technology integration (68% schools had devices, but use was limited to PowerPoint/video; teachers struggled with data analysis/collaborative platforms), and limited inquiry-based design skills (only 24% could design IBL's evidence gathering/explanation construction; 92% never fully applied Kolb's EL) (Sutimah et al., 2024; Guru Inovatif, 2024; Chen et al., 2021; Kolb, 1984). Teachers' primary needs were practical training in integrating IBL/EL with technology, assessing sci-digital literacy, and developing project-based materials.

Synthesis and Recommendation: The consistent findings from curriculum, student, and teacher analyses underscore the critical need for the EXARIS model. It addresses the misalignments between

Merdeka Curriculum demands and IPAS implementation, students' low sci-digital literacy due to passive methods, and teachers' insufficient digital pedagogy and inquiry design skills. The EXARIS model is proposed as an integrative solution combining IBL (Chen et al., 2021), EL (Kolb, 1984), and Berlo's (1960) scientific communication framework with a digital-augmented inquiry approach. This study aims to develop an empirically tested prototype with operational guidelines for teachers, aligning with Indonesia's "Golden Generation 2045" roadmap (Permendikbudristek No. 262/2024).

4.2. Design Phase

The EXARIS Learning (Explorer, Analysis, Reflection, Integrate, Share) learning model was designed as a refined integration of Inquiry-Based Learning (IBL) and Experiential Learning (EL), carefully tailored to elementary school students' cognitive development, learning needs, and pedagogical principles (Bybee, 2015; Kolb, 1984). Its five-phase syntax systematically combines inquiry and experiential approaches, as shown in Table 1.

Table 1. Overview of the EXARIS Learning Model Based on Scientific Communication

EXARIS Syntax	Theoretical Support	Empirical & Combined Model Support
Phase 1: Explorer	Psychological Theory (Constructivism): Stimulates curiosity and activates students' prior knowledge schemas as a foundation for constructing new knowledge (Piaget, 1970). Communication (David Berlo): The Source (teacher) sends a message (phenomenon/problem) that engages the Receiver (student), prompting initial feedback in the form of questions. Behaviorism: Initial stimuli can trigger exploratory responses (Skinner, 1953). Connectivism: Encourages initial exploration within information networks, forming early connections with new ideas (Siemens, 2005).	Combination of IBL & EL: Questioning Phase (IBL) + Concrete Experience (Experiential Learning). Empirical: Studies show that an engaging opening phase increases student motivation and involvement in inquiry learning (Darling-Hammond et al., 2020). The use of simulations or interactive videos in this phase has been proven effective for initial exploration (Chu et al., 2017).
Phase 2: Analyze	Constructivism: Students actively process data and construct understanding through analysis rather than passive reception (Vygotsky, 1978). Communication (Berlo): Scientific data undergoes encoding (processing) and decoding (interpretation), with internal communication channels (thinking) actively engaged. Behaviorism: Reinforces investigative behavior through feedback from digital analysis tools that guide toward conclusions. Connectivism: Utilizes digital networks for data collection, organization, analysis, and evaluation of sources (Downes, 2008).	Combination of IBL & EL: Investigation Phase (IBL) + Reflective Observation (Experiential Learning). Empirical: Research shows that evidence-based data analysis enhances students' critical thinking and scientific reasoning (Kuhn, 2015). The use of digital data analysis tools can improve efficiency and accuracy (Krajcik & Shin, 2015).
Phase 3: Reflection	Constructivism: Metacognition and internalization of meaning occur as students reflect on their experiences and analysis results (Kolb, 1984).	Combination of IBL & EL: Conclusion Phase (IBL) + Abstract Conceptualization (Experiential Learning).

EXARIS Syntax	Theoretical Support	Empirical & Combined Model Support
	Communication (Berlo): Internal and interpersonal feedback occurs through discussion, allowing students to evaluate the messages (experiences) and their processes. Behaviorism: Reflection reinforces successful learning behavior and identifies areas for improvement. Connectivism: Integrates personal thinking with network-based insights through discussions and shared reflections (Siemens, 2005).	Empirical: Reflection has been shown to improve conceptual understanding and knowledge transfer by helping students connect experience to theory (Kolb & Kolb, 2017). Digital reflection journals are effective empirical tools (Roberts, 2012).
Phase 4: Integrate	Constructivism: Builds more complex cognitive structures by connecting new ideas to existing schemas (Piaget, 1970). Communication (Berlo): Synthesizes various messages (inquiry results, reflections, new information) into a coherent whole. Behaviorism: Positive reinforcement when students successfully synthesize and generalize concepts promotes integrative behavior. Connectivism: Forms connections across nodes (information, concepts, disciplines) in students' knowledge networks, enabling holistic understanding (Downes, 2008).	EXARIS Innovation: A key differentiator that addresses the limitations of IBL/EL in knowledge generalization and transfer. Empirical: Abstract conceptualization and knowledge synthesis are crucial for deep understanding and transferability (Kolb & Kolb, 2017). The use of concept maps or digital diagrams effectively visualizes integration (Krajcik & Shin, 2015).
Phase 5: Share	Social Constructivism: Knowledge becomes more robust when socially communicated and validated (Vygotsky, 1978). Communication (Berlo): Represents the peak of communication, where the Source (student) composes a clear, persuasive message for the Receiver (audience) through selected Channels (oral or digital), expecting feedback. Behaviorism: Positive reinforcement (appreciation, questions) from the audience encourages effective communication behavior. Connectivism: Sharing knowledge within networks contributes to collective understanding and digital interaction (Siemens, 2005).	Combination of IBL & EL: Communication Phase (IBL) + Active Experimentation (Experiential Learning). Empirical: Effective scientific communication improves student understanding, presentation skills, and digital literacy (Krajcik & Shin, 2015). Participation in scientific discussions and public presentations enhances learning (Kuhn, 2015). The Integrate and Share phases in EXSARIS can be designed to cultivate soft skills and social responsibility through action-based learning, Rahmat, H., Chong, O. L., & Mashudi, R. (2020).

This model also outlines the reaction principle, which redefines the teacher's role from a mere transmitter of information to a facilitator of scientific dialogue. Teachers are expected to respond to students' inquiries with evidence-based counter-questions (probing questions), guiding the communication process using Berlo's SMCR model (1960) to ensure that scientific messages are effectively conveyed through various digital channels. The social system of the EXARIS Learning

Model is built on a spirit of collaboration, with students taking on dynamic roles such as data analyst, digital creator, and science communicator to create a mini scientific ecosystem in the classroom (Voogt & Roblin, 2012). The role of teachers as researchers and co-designers of innovative teaching models is crucial in developing instructional practices that integrate ICT and promote 21st-century skills (Binsaleh, S., & Binsaleh, M, 2020).

4.2.1. Product Design EXARIS Learning Model Book

The EXARIS Learning Model book is systematically structured into four complementary main sections. The first section discusses the rationale for developing the model, including the background and urgency of implementing the EXARIS model in the context of modern learning. It elaborates on the philosophical and practical justifications for the need to design this innovative learning model. The second section presents the theoretical foundations that underpin the EXARIS model, integrating various contemporary learning theories from leading educational and psychological scholars. These theories are presented comprehensively to provide a solid conceptual framework for the model's development. Overall, this book is designed to guide educators in understanding and implementing the EXARIS Model in a holistic manner, from conceptual underpinnings to classroom practice.



Figure 4. Cover of the Learning Model Book: Before and After Revision

4.2.2. Product Design Teacher and Student Guidebook

This guidebook supports teachers in managing instruction using the EXARIS Learning Model. It includes: (a) model components; (b) model syntax; (c) syntax descriptions; and (d) instructional tools comprising: (1) Teaching Module/Lesson Plan (RPP); (2) Test blueprint for knowledge assessment; (3) Test items for knowledge and scientific literacy skills; (4) Answer key for knowledge tests; (5) Digital literacy skills assessment blueprint; (6) Digital literacy assessment rubric; (7) Student worksheets (LKPD); (8) LKPD answer key; and (9) LKPD assessment rubric. The EXARIS Student Guidebook is designed as a primary reference to support a structured and systematic learning process. It provides clear instructions to help students deepen and apply their understanding of each topic. By following the guidance, students can develop independent learning habits and effectively complete each stage of the learning process.

4.3. Development Phase

This stage aims to design a scientifically communicative model handbook, teacher guidebook, and student guidebook with high validity, ease of implementation, and practical effectiveness. Development follows three key stages: validation, revision, and testing, each ensuring quality and appropriateness. In the validation and revision stage, instruments were evaluated by a validator team comprising three expert validators from universities. After expert validation, reliability testing was

conducted using the Intraclass Correlation Coefficient (ICC) method to ensure measurement consistency. ICC was selected for its ability to quantify agreement levels across repeated measurements. Validation assessed the effectiveness, conceptual coherence, and syntactic appropriateness of the EXARIS learning model. Validators examined: Expert input played a pivotal role in refining the EXARIS learning model, focusing on how each component contributes to learning objectives, the model's structural integrity, its social systems and reaction principles, and the design of its support system. This comprehensive feedback led to significant enhancements, including standardizing syntax naming for consistency, ensuring theoretical grounding for all terms, synthesizing only compatible pedagogical models, and developing application-focused assessment metrics to measure critical thinking in scientific literacy. Additionally, expert recommendations clarified teacher and student roles, detailing concrete actions for each phase, and enriched the exploratory stage with problem-based contexts. This rigorous refinement process thoroughly prepared the model for broad implementation, ultimately ensuring the optimal enhancement of student learning experiences. Expert validation results indicate that the construction of the model book, both in terms of layout and language, falls under the "highly valid" category. Table 2 presents the validation results of the EXARIS model book on the theme of "Caring for Living Beings" in Science and Social Studies (IPAS) learning.

Table 2. Validation Results of the EXARIS Learning Model Development

No	Aspect Evaluated	Score	Remark
1	Book Construction	0,178	Highly Valid
2	Model Rationale	03.50	Valid
3	Supporting Theories	0,178	Highly Valid
4	Structure of the EXARIS Learning Model		
	a. Syntax	0,174	Highly Valid
	b. Social System	0,167	Valid
	c. Reaction Principles	0,174	Highly Valid
	d. Support System	0,173	Highly Valid
	e. Instructional & Accompaniment Impact	0,177	Highly Valid
5	Learning Implementation	0,171	Highly Valid

The EXARIS learning model was developed with a highly valid book construction, achieving a score of 3.75. The book's structure is designed to systematically support the model's application, ensuring effectiveness in the learning process. The model rationale scored 3.50, indicating that this concept has a strong and relevant foundation. The model was developed by considering educational needs and implementation effectiveness across various contexts. The supporting theories have a validity score of 3.75, confirming that the principles used in this model are based on well-established educational theories. The presence of these theories ensures that the EXARIS learning approach can be optimally implemented.

4.3.1. Focus Group Discussion (FGD)

A virtual Focus Group Discussion (FGD) via Zoom on February 18, 2025, systematically developed the scientific communication-based EXARIS learning model using the ADDIE framework (Analysis, Design, Development, Implementation, Evaluation). This structured, evaluation-driven process aimed to enhance scientific communication, integrate science and digital literacy, and refine the learning syntax. Expert feedback was integrated to ensure validity, practicality, and effectiveness: Prof.

Festiyed stressed explicit science/digital literacy integration (including information validation) and stronger academic justification through model analysis; Dr. Rizal Muharram advocated for consistent stages, teacher tech mentoring, robust digital literacy theories (Hobbs, Belshaw, Payton, Hague), connectivism, and graphical model comparisons; Prof. Syafrri Ahmad emphasized structured proposal materials aligned with learning steps; Mr. Budi Setiawan proposed strengthening digital literacy indicators for social integration and systematic instructional impact, noting the model's project-based learning (PBL) design effectively replaces traditional teaching by promoting active collaboration, real-world problem-solving, and authentic lessons; Mrs. Wiwin Darmanti suggested more engaging book covers. Collectively, these refinements prepared the EXARIS model for implementation.

4.4. Implementation Phase

The implementation phase involved a limited trial, serving as an initial qualitative evaluation focusing on content validity rather than outcomes. The supporting materials and products were qualitatively assessed as "good" and deemed ready for application. The trial was conducted at the Indonesian School Abroad (SILN) in Kota Kinabalu to evaluate the effectiveness of a 20-item multiple-choice test on the theme "Our Earth is in Danger", covering environmental issues like global warming, pollution, and ecosystem degradation. Results were used to refine the test instrument and develop more relevant learning materials. Results of Science Literacy Knowledge Test (Limited Trial) Table 3.

Table 3. Learning Outcomes (Knowledge Aspect) – Limited Trial

Class	Avg. Pretest	Avg. Posttest	Improvement	N-Gain	Category
Experimental	60.71	85.89	+25.18	0.68	Higt
Control	60.50	77.33	+16.83	0.512	Medium
Difference	+0.21	+8.56	+8.35	+0.168	

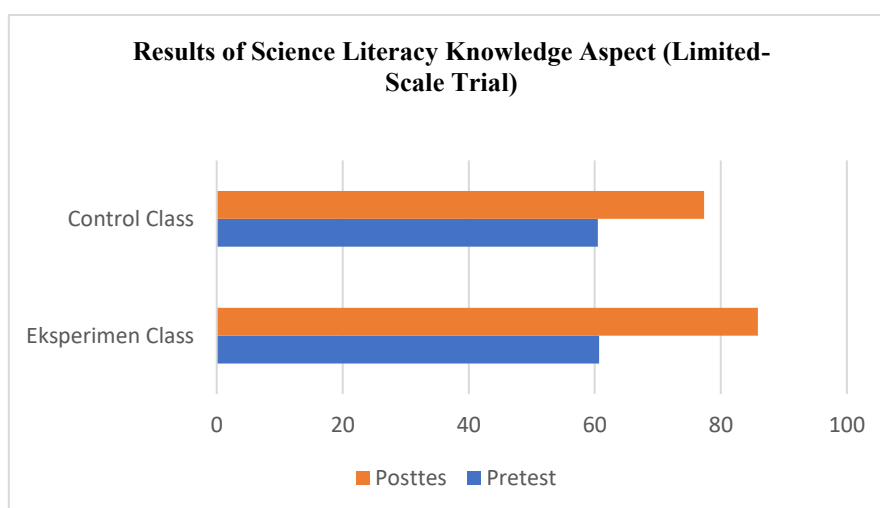


Figure 5. Knowledge Aspect Results Graph

The EXARIS model demonstrated significant effectiveness: Experimental class: 25.18-point increase (60.71 → 85.89), N-Gain 0.68 (High) (Hake, 1999) Control class (conventional): 16.83-point increase, N-Gain 0.512 (Medium). The N-Gain difference (0.168) highlights EXARIS's superiority in enhancing learning outcomes. The Explorer-Analyze-Reflection-Integrate-Share (EARIS) framework fostered deeper conceptual understanding through scientific communication. Recommendations Further refinements could target an N-Gain >0.7. Broader implementation with adjustments is recommended to optimize results. Opportunities exist to adapt the model for diverse learning

contexts. Follow-Up Analysis Based on Table 4, prerequisite tests (e.g., normality tests for experimental/control classes) were conducted using SPSS 25 (see subsequent tables for details). Table 4. Normality Test Results of Learning Outcomes.

Table 4. Result Normality Test

Result	Class	Kolmogorov-Smirnov ^a			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Pretest A (Class Control)		,116	30	,200*	,961	30	,325
Posttest A (Class Control)		,165	30	,037	,908	30	,013
Pretest B (Class Eksperimen)		,201	28	,005	,883	28	,005
Postes B (Class Eksperimen)		,186	28	,014	,911	28	,021

The Shapiro-Wilk normality test results indicate that both pretest and posttest data in the two classes generally follow a normal distribution. In Class A (control group): Pretest significance value: 0.325 (>0.05) - normal distribution, Posttest significance value: 0.13 (>0.05) - normal distribution. In Class B (experimental group): Posttest significance value: 0.21 (>0.05) - normal distribution, Pretest significance value: 0.05 (exactly at the threshold). The Shapiro-Wilk normality test results demonstrate that both pretest and posttest data in the two classes generally follow a normal distribution: Class A (Control Group): Pretest significance: 0.325 (>0.05) - normally distributed Posttest significance: 0.13 (>0.05) - normally distributed. Class B (Experimental Group): Posttest significance: 0.21 (>0.05) - normally distributed. Pretest significance: 0.05 (threshold value)

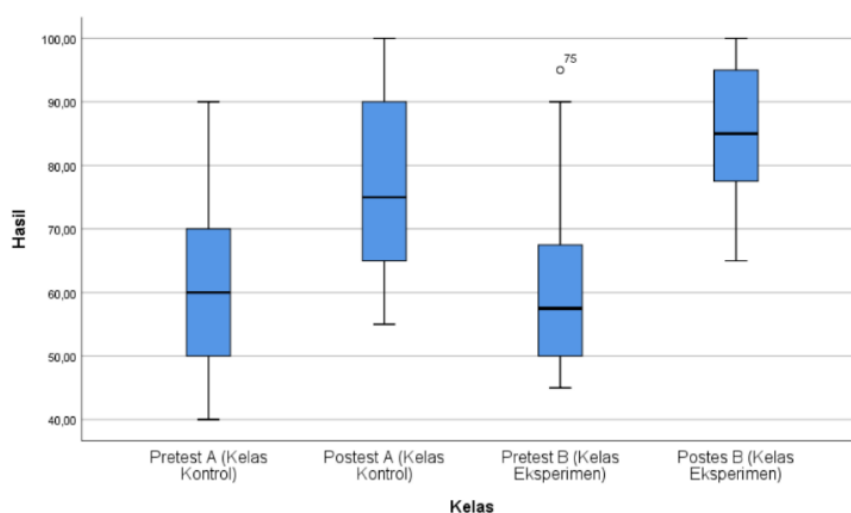


Figure 6. Normality Test Results for Science Literacy Knowledge Assessment

Using the conventional $\alpha=0.05$ threshold, all values above this level confirm normal distribution. The experimental group's pretest result is exactly at the threshold value, indicating borderline normality. This suggests the data meet the parametric test assumptions for subsequent analyses. The visual representation in Table 5 further supports these statistical findings Test of Homogeneity of Variance.

Table 5. Test of Homogeneity of Variance

	Levene Statistic	df1	df2	Sig.
Based on Mean	2,281	1	56	0,137
Based on Median	1,364	1	56	0,248
Based on Median and with adjusted df	1,364	1	49,473	0,248
Based on trimmed mean	2,17	1	56	0,146

Statistical assumption validation confirmed suitability for parametric analysis. Shapiro-Wilk tests indicated normal distribution for all pretest and posttest data ($p > 0.05$), except Class B's pretest, which equaled the $\alpha=0.05$ threshold, with no visual deviations from normality observed. Levene's Test demonstrated homogeneous variances across posttest measures: Based on Mean ($p=0.137$), Median ($p=0.248$), and trimmed mean ($p=0.146$), all exceeding $\alpha=0.05$. With both normality and homogeneity assumptions satisfied, independent samples t-tests were appropriately conducted to examine group differences. This rigorous fulfillment of parametric prerequisites ensures reliable interpretation of comparative results between instructional approaches and strengthens validity claims regarding outcome differences.

4.4.1. Paired Sample T-Test

After the experimental class pretest and posttest data met the assumptions of normality based Upon confirming parametric assumptions via Shapiro-Wilk ($p>0.05$ for normality) and Levene's ($p>0.05$ for homogeneity) tests, a Paired Samples T-Test was conducted to assess the EXARIS model's impact on learning outcomes. The analysis revealed a statistically significant mean score increase of 25.179 points ($SD = 10.045$) between pretest and posttest measurements within the experimental group, with a standard error of 1.898 indicating high precision. The 95% CI [-29.073, -21.284] confirmed posttest superiority, while the substantial t-value (-13.264, $df=27$, $p<0.001$) decisively rejected the null hypothesis ($\alpha=0.05$). These results validate that EXARIS implementation significantly enhanced IPAS Phase C learning outcomes for the 'Our Threatened Earth' theme. Separately, an Independent Samples T-Test was performed after verifying identical parametric assumptions, comparing outcomes between EXARIS and traditional instruction groups in Table 6.

Table 6. Paired Samples test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
		Pair 1	Pretes - Posttest	-25,179	10,045	1,898			

4.5. Evaluation Phase

4.5.1. Analysis of Scientific Literacy Knowledge Aspect Results Field Scale Test

This stage involved a field-scale test of the EXARIS (Explore, Analyze, Reflection, Integrate, and Share) learning model, based on scientific communication, to enhance elementary students' scientific

literacy knowledge (cognitive) aspect concerning the topic "Our Threatened Earth." The field scale test was conducted in two distinct educational settings: Sekolah Indonesia Luar Negeri (SILN) Jeddah, Saudi Arabia, representing a multicultural context, and Sekolah Dasar Negeri Percobaan Kota Padang, representing the national education system. This aimed to evaluate the model's validity and effectiveness across diverse learning environments. Through stages of exploration, critical analysis, reflection, concept integration, and scientific knowledge sharing, the EXARIS model is designed to strengthen students' understanding of environmental issues while developing scientific communication skills. Domestically and abroad. Further details are presented in Table 7.

Table 7. Comparison of Average Learning Outcomes and N-Gain of Scientific Literacy

School	Group	Average Pretest	Average Posttest	N-Gain	N-Gain Category
Sekolah Indonesia Luar Negeri Jeddah, Saudi Arabia	Experiment	69.46	91.43	0.72	High
	Control	65.00	80.33	0.44	Medium
SD N Percobaan Kota Padang	Experiment	69.00	91.50	0.72	High
	Control	67.84	84.58	0.52	Medium

Based on the descriptive analysis, both quantitatively and qualitatively, a consistent and significant pattern is observed in both schools, Sekolah Indonesia Luar Negeri Jeddah and Sekolah Dasar Negeri Percobaan Kota Padang, regarding the results of the scientific literacy cognitive knowledge test. Quantitatively, the average pretest scores in both experimental and control groups across both schools showed relatively close figures, indicating that both groups had comparable initial scientific literacy knowledge levels before the intervention. This is qualitatively important as it ensures the validity of the comparison between the two groups. However, a striking difference began to emerge in the average posttest scores. The experimental classes in both schools achieved very high posttest scores, above 90, signifying strong mastery of scientific literacy material after the treatment. Meanwhile, the control classes also experienced improvement, but their posttest scores were significantly lower compared to the experimental classes, highlighting the positive effect of the treatment in the experimental classes in Figure 7.

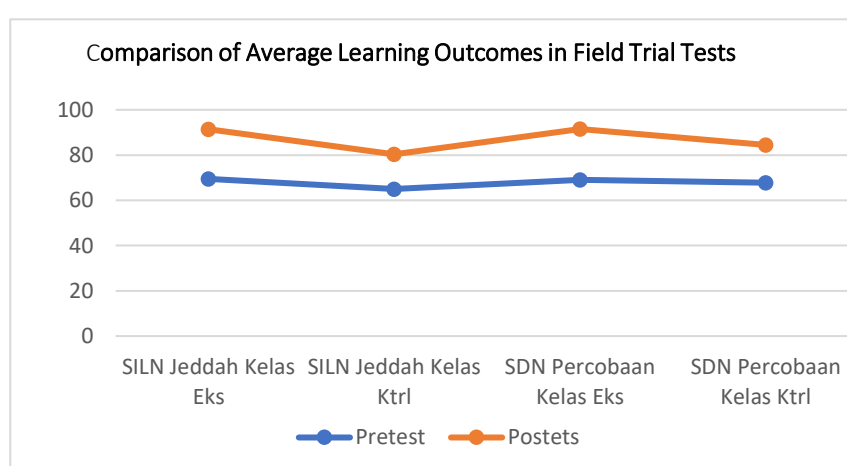


Figure 7. Comparison of Average Learning Outcomes in Field Trial Tests

Based on both quantitative and qualitative descriptive analyses, a consistent and significant pattern was observed in the scientific literacy cognitive knowledge test results across both schools: Sekolah Indonesia Luar Negeri Jeddah and Sekolah Dasar Negeri Percobaan Kota Padang. Quantitatively, the average pretest scores for both the experimental and control classes in both schools were relatively close, indicating that the two groups possessed comparable initial levels of

scientific literacy knowledge prior to the intervention. This is qualitatively important as it ensures the validity of the comparison between the groups. However, a marked difference became apparent in the average posttest scores. The experimental classes in both schools achieved very high posttest scores, exceeding 90, signifying a strong mastery of scientific literacy material following the treatment. Meanwhile, the control classes also showed improvement, but their posttest scores were significantly lower than those of the experimental classes, highlighting the positive effect of the experimental treatment in Figure 8.

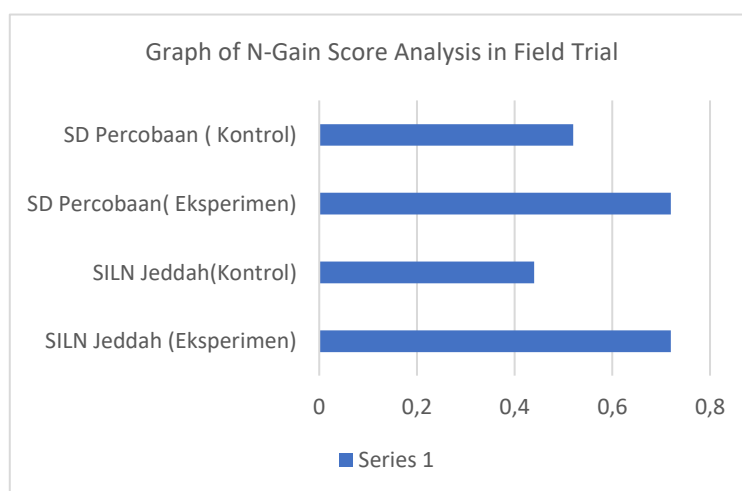


Figure 8. Graph of N-Gain Comparison for Scientific Literacy Knowledge Aspect

4.5.2. Analysis of Digital Literacy Skills Test Results Limited-Scale Field Test

This limited-scale field test was conducted at Sekolah Indonesia Luar Negeri (SILN) Kota Kinabalu, Malaysia, to assess the effectiveness of the EXARIS (Explorer, Analyze, Reflection, Integrate, Share) learning model in enhancing students' digital literacy skills. The trial involved 28 students in the experimental group compared to 30 students in the control group, focusing on four aspects of digital literacy as defined by OECD, 2022: (1) accessing information, (2) using technology, (3) digital collaboration, and (4) digital communication. The EXARIS model was implemented through a project-based thematic learning approach on the environmental issue "Our Threatened Earth," wherein students progressively explored digital sources, analyzed data, reflected on findings, integrated technology, and shared results via digital platforms. The results are presented in Table 8 below:

Table 8. Average Digital Literacy Skills in Limited-Scale Test

Digital Literacy Skill	Experimental Class	Control Class	Difference
Accessing Digital Information	3.82	2.87	+0.95
Using Technology	3.71	2.83	+0.88
Digital Collaboration	3.64	2.63	+1.01
Digital Communication	3.13	2.87	+0.26
Total Average	14.30	10.20	+4.10

The rubric-based assessment of digital literacy skills in the EXARIS model's limited-scale test revealed a significant difference between the experimental (average 14.3) and control (10.2) classes, confirming the model's effectiveness in enhancing students' digital literacy. The most prominent improvements were observed in digital collaboration and technology use, indicating a strengthening of both technical and socio-digital skills. Students utilizing the EXARIS model also showed significant progress in accessing digital information (evaluating credibility, advanced searches) and digital communication (presentations, online discussions). While the majority of students became

'Competent Users' (64.3%), the presence of 'Digital Pioneers' (21.4%) and 'Developing Learners' underscores the necessity for a differentiated approach and tailored scaffolding in EXARIS implementation. Table 9 Digital Literacy Skills Normality Test Results.

Table 9. Test of Normality

	Kolmogorov-Smirnov ^a			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
kontrol	,149	28	,113	,955	28	,265
ekperimen	,151	28	,104	,963	28	,404

Based on the data in Table 9 the normality test results for the research data revealed that all data from both research groups are normally distributed. For the control group, the Kolmogorov-Smirnov test yielded a significance value of 0.113 ($p > 0.05$), and the Shapiro-Wilk test showed a significance value of 0.265 ($p > 0.05$). Similar results were found in the experimental group, where the Kolmogorov-Smirnov test produced a significance value of 0.104 ($p > 0.05$), and the Shapiro-Wilk test indicated a significance value of 0.404 ($p > 0.05$). The consistency of these results across both normality test methods for both research groups convincingly demonstrates that all data in this study meet the assumption of normality. Subsequently, a Homogeneity Test will be conducted, and its results can be seen in the following table 10.

Table 10. Test of Homogeneity of Variances

		Levene Statistic	df1	df2	Sig.
Hasil	Based on Mean	,063	1	56	,803
	Based on Median	,044	1	56	,835
	Based on Median and with adjusted df	,044	1	55,899	,835
	Based on trimmed mean	,066	1	56	,798

Based on Levene's test for homogeneity of variances, all calculations indicate that the research data satisfy the assumption of equal variances. The obtained Levene Statistic values are very low, ranging from 0.044 to 0.066, with degrees of freedom $df1 = 1$ and $df2 = 56$. All significance values (p-values) are well above the $\alpha = 0.05$ significance level: 0.803 (based on mean), 0.835 (based on median), 0.835 (based on median with adjusted df), and 0.798 (based on trimmed mean). The consistency of these results reinforces the conclusion that the data variances of the compared groups are homogeneous in Table 11.

Table 11. Paired Samples T-Test Results

				Paired Differences		t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference			
					Lower	Upper		
Pair 1	Hasil - Kelas	1,78879	,45596	,05987	1,66890	1,90868	29,878	,000

A Paired Samples T-Test confirmed the EXARIS learning model's significant effectiveness in boosting students' digital literacy. Post-EXARIS implementation, digital literacy scores increased by an average of 1.79 points ($p < 0.001$), with a 95% confidence interval entirely above zero, affirming a genuine and significant improvement. A subsequent field-scale test, comparing EXARIS in two diverse

school settings (SILN Jeddah and SD N Percobaan), further supported its efficacy, showing consistently higher digital literacy scores in experimental groups across all indicators compared to control groups. Based on the data in Table 48, the statistical analysis using a Paired Samples T-Test confirmed that the hypothesis stating the EXARIS learning model is effective in enhancing students' digital literacy can be significantly accepted. The test results show an average increase of 1.79 points (Mean Difference = 1.78879) in students' digital literacy after the implementation of the EXARIS model, with a standard deviation of 0.45596, indicating consistent improvement across the entire sample. The t-value of 29.878 with 57 degrees of freedom (df) yielded a significance of 0.000 ($p < 0.001$), confirming that this improvement was not coincidental but genuinely influenced by the EXARIS learning model intervention. Furthermore, the 95% confidence interval for the mean difference (1.66890 to 1.90868) is entirely above zero, further strengthening that the increase in students' digital literacy is real and significant.

4.5.3 Analysis Results of Field Scale Digital Literacy Skills Test

This study evaluated the effectiveness of the EXARIS (Explorer, Analyze, Reflection, Integrate, Share) learning model in improving students' digital literacy on the theme "Our Threatened Earth" (IPAS Phase C) at two different locations. This field scale test aimed to assess how the EXARIS model, based on a scientific approach and digital technology integration, can develop students' digital literacy competencies within an environmental learning context, while also identifying necessary adaptations for each school setting.

Table 12. Field Test Results Comparison of Digital Literacy Skills

No	Digital Literacy Indicator	SILN Jeddah		SDN Percobaan	
		Experimental	Control	Experimental	Control
1	Information Access	3.85	2.40	3.78	2.35
2	Technology Utilization	3.80	2.55	3.72	2.50
3	Digital Collaboration	3.70	2.20	3.65	2.15
4	Digital Communication	3.50	2.35	3.72	2.30

For the "Accessing Information" indicator, the experimental class at SILN Jeddah scored 3.85 compared to 2.40 in the control class, and at SD Percobaan Padang, 3.78 compared to 2.35. This increase of approximately 1.4 points highlights the success of the "Explorer" phase in EXARIS, which trains students to evaluate the credibility of digital sources using the CRAAP test (Currency, Relevance, Authority, Accuracy, Purpose) and to utilize academic databases such as Google Scholar. The "Using Technology" indicator also showed substantial improvement—by 1.25 points in Jeddah and 1.22 points in Padang through the integration of digital environmental simulation tools and basic data processing applications.

5. Discussion

5.1. Validity of the EXARIS Learning Model Design

The validation results indicate that the EXARIS learning model holds a very high level of validity, with most components rated as "Very Valid" or "Valid." This reflects expert consensus on its feasibility and appropriateness for classroom implementation. The consistently high scores across components confirm that the model is holistically designed, with all elements working synergistically to achieve learning goals. The solid conceptual framework provides a strong foundation for its development and supports its potential to enhance both scientific and digital literacy. The rational aspect scored 3.50

("Valid"), indicating that the model's conceptual justification—its relevance, objectives (enhancing scientific and digital literacy), and the use of scientific communication as a foundation—is academically sound and pedagogically justifiable. This rationale is essential in explaining the model's alignment with the theme *"Our Earth is in Danger"* and its relevance in addressing current learning challenges. The book construction aspect received a score of 3.75 ("Very Valid"), confirming that the student and teacher manuals are well-structured, logically organized, and user-friendly. Clear and systematic content facilitates effective scientific communication, reduces ambiguity, and allows students to progressively build knowledge. Furthermore, the integration of digital resources and activities enhances digital literacy, while interactive features promote effective technology use. The supporting theory aspect also scored 3.75 ("Very Valid"), affirming that the model is grounded in current, evidence-based pedagogical theories relevant to science and digital literacy development. This theoretical foundation ensures the model is not based on intuition but on proven educational research. Aligned with David Berlo's scientific communication model, the EXARIS framework emphasizes the importance of message clarity, and the characteristics of both the sender (teacher) and receiver (student) to ensure effective knowledge transmission. Lastly, the syntax component scored 3.71 ("Very Valid"), indicating that the model's five phases—Explorer, Analyze, Reflection, Integrate, and Share—are logically sequenced and coherent. This structured syntax supports scientific communication by facilitating the progressive and systematic exchange of ideas, arguments, and information. It also helps teachers guide students through each phase effectively while enabling students to follow a clearthinking process, as envisioned in Berlo's communication model.

5.2. Practicality of the EXARIS Learning Model

5.2.1. Teacher Response

Observation data from two different schools—Sekolah Indonesia Luar Negeri (SILN) Jeddah and SD Percobaan Padang—indicate a high level of practicality in implementing the EXARIS model. Both schools reported a strong average score of 3.75 (on a 1–4 scale) across key aspects, reflecting positive teacher perceptions. Teachers found the model easy to understand, clearly structured, and smoothly executable without complex preparation—facilitating their role as learning facilitators in line with constructivist principles.

5.2.2. Student Response

Student feedback at SILN Jeddah showed an average implementation rate of 91.67%, indicating an effective and engaging learning experience. The high clarity and structured nature of the model minimized confusion and cognitive overload, aligning with Cybernetic Theory, where low entropy and strong feedback loops support efficient learning systems. Students received inputs (instructions, materials) clearly and responded actively, suggesting that the EXARIS model effectively managed information flow and feedback. Moreover, students rated the perceived benefits of EXARIS very highly (91.67%), reinforcing that the model effectively achieved its learning goals—such as enhancing understanding, motivation, and skills. According to cybernetic principles, this positive feedback reflects a self-regulating system where learners are actively engaged and motivated by meaningful outcomes.

5.3. Effectiveness of the EXARIS Learning Model

The EXARIS model was successfully implemented with an average effectiveness of 92.24%, improving to 94.44% in later sessions, demonstrating strong teacher and student adaptability and long-term sustainability. Students actively engaged in all phases, particularly in information processing and environmental action plans (score 4.00). Exploration and analysis were conducted effectively (3.83–4.00), supporting experiential learning and problem-solving. While students demonstrated strong scientific literacy, particularly in identifying environmental issues (3.17–3.50)

and executing real-world actions (4.00), they need to improve in designing data-driven action plans. Digital literacy also advanced, especially in collaboration and communication (3.67), aligning with Social Constructivist principles. However, critical evaluation of digital sources needs reinforcement (3.50). A comparative analysis between SILN Jeddah and SD Percobaan Padang confirms EXARIS's adaptability, achieving similar success across different school environments.

6. Conclusion

The development of the EXARIS learning model and its supporting materials (model book, teacher guide, and student workbook) meets the criteria of validity, practicality, and effectiveness. The model demonstrated high validity (average 3.67–4.00 for the model; 3.75 for guides), based on relevant theory and strong internal consistency. Practically, EXARIS is highly implementable, as evidenced by high teacher observation scores (3.75) during both limited and full-scale trials. In terms of effectiveness, learning activities reached 91.67–94.44% implementation, with active student engagement and significantly improved science literacy. The experimental class achieved a high N-Gain score (0.68–0.72), well above the control group (0.44–0.52). In summary, EXARIS is a proven, innovative solution that is valid, practical, and effective for enhancing students' science and digital literacy.

7. Suggestion

Based on the results of the EXARIS model development, several recommendations are proposed to support its effective implementation and future development. First, schools are encouraged to integrate the EXARIS model into their curriculum planning, particularly within the IPAS (Science and Social Studies) subject for Phase C (Grade 6), as it aligns with the objectives of the Merdeka Curriculum and promotes scientific and digital literacy. Second, teacher training programs should include specific modules on the EXARIS model to ensure that educators are well-prepared to implement its phases effectively, especially during the exploration and integration stages. Third, although the model was applied to the theme "Our Endangered Earth," it is recommended that future studies adapt the model across different themes and subjects to assess its scalability and relevance in varied educational contexts. Additionally, to enhance digital literacy outcomes, the development of supporting digital learning resources—such as interactive worksheets, digital journals, and educational videos—should be prioritized, ensuring accessibility and alignment with each phase of the EXARIS model. Lastly, educational policymakers and school leaders should support the dissemination and broader application of the model through professional development initiatives, webinars, and international collaborations. These recommendations aim to maximize the impact of the EXARIS model and contribute to improving students' 21st-century competencies in a sustainable and systematic way.

Declarations

Author Contributions. Exsaris Januar led the conceptualization of the study, developed the EXARIS learning model, conducted the field research, and drafted the initial manuscript.

Prof. Dr. Nurhizrah Gistituati, M.Ed. (Corresponding Author), provided academic supervision, contributed to the refinement of the model, validated the research framework, and conducted critical manuscript review and editing.

Dr. Yanti Fitria, M.Pd., contributed to the design of research methodology, validation of instruments, and interpretation of findings.

Prof. Dr. Alwen Bentri, M.Pd., was responsible for the theoretical framework, literature synthesis, and academic consultation throughout the research process.

Dr. Muhammadi, M.Pd., supported the data analysis process, conducted statistical testing, and contributed to the visualization and presentation of research results.

All authors have read and approved the final version of the manuscript for publication.

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Ethical Approval. The study adhered to ethical standards involving human participants, including respect for privacy, informed consent, and voluntary participation. Ethical approval was obtained from the Research Ethics Committee of Universitas Negeri Padang (Approval No. 1390/UN35.1.35/ETIK/2024).

Data Availability Statement. The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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