Reframing the earth science handbook to cultivate pre-service teachers' generic science skills and problem-solving

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Abstract
The highly contextual nature of Earth Science content in relation to students requires teachers to possess strong generic science skills and problem-solving abilities to ensure optimal knowledge transfer in the learning process. This study aimed to conduct a needs analysis to inform the design of the Earth Science handbook and to evaluate their validity, practicality, and readability. This research is part of a two-year Research and Development (R&D) project. In the first year, the development of teaching materials employed the 4D model, limited to three stages: define, design, and develop. The define stage began with an analysis of students' needs regarding Earth Science teaching materials through literature review and field observations. The design stage involved organizing chapters, constructs, and content of the materials based on the results of the needs analysis. The output of this stage was the initial draft of the teaching materials. The development stage included expert-judgment validation, practicality testing by lecturer-practitioners, and readability testing by students. The results indicated that the developed Earth Science teaching materials were categorized as highly valid (Gregory's Index = 1.00), highly practical (mean score = 3.73), and excellent readability (mean score = 3.66). This study concludes that Earth Science teaching materials are needed to enhance students' generic science skills and problem-solving abilities. The developed materials are feasible for dissemination and effectiveness testing. The findings provide practical implications for improving Earth Science instruction and support the development of competency-based learning aligned with 21st-century educational demands.

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1. Introduction

Earth Science is one of the core subject areas that prospective science teachers find valuable, as it provides a fundamental understanding of the Earth system and its relevance to everyday life. Earth Science subject material includes the natural processes that shape it, its internal structure, natural phenomena such as earthquakes and volcanic activity, climate, weather, oceans, natural resources, and the impacts of human activities (Pujani et al. 2022). It also encompasses the study of natural resources such as petroleum, natural gas, and minerals, as well as their responsible utilization. At the junior secondary school level (junior high school), Earth Science content is also frequently included in academic competitions at both national and international levels for junior and senior high school students. These conditions require prospective science teachers to possess strong mastery of Earth Science, both declarative and procedural knowledge, enabling them to understand the urgency and relevance of this content for students' daily lives (Mclaughlin & Bailey., 2023). So, Knowledge of Earth Science is essential for prospective science teachers to enable them to guide students in understanding natural resources and the interrelationships among land, oceans, the atmosphere, and life on Earth.

Practically, at school Science teachers are often responsible for preparing students for Earth Science competitions or Olympiads. Conceptual explainers in Geocience are highly contextual for students, including phenomena such as rainfall formation, rainbows, and geothermal energy sources(Nastiti et al. 2024). Hence, strengthening science teachers' competence in Geocience is

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increasingly important. Science teachers must involve questioning, seeking answers, understanding, and refining explanations about natural phenomena through systematic approaches. Through science learning, students' curiosity, open-mindedness, critical thinking, problem-solving skills, environmental awareness, and responsiveness can be cultivated(Sasidharan et al., 2023). Accordingly, higher education institutions responsible for pre-service science teacher education are required to ensure that prospective teachers develop robust conceptual understanding, generic science skills, and problem-solving competence through curriculum-aligned Earth Science instruction.

On the other hand, observations of Earth Science instruction in the Science Education Study Program at Universitas Pendidikan Ganesha (Undiksha) indicate that mastery of Earth Science concepts remains relatively low. Only about 15% of students achieve an A grade with a score in the upper 85.0 range, while most obtain grades of B, with scores between 71.0 and 84.0. Several contributing factors were identified: (1) the quality of the instructional process is still suboptimal, influenced by factors such as instructor competence and learning facilities; (2) the lack of adequate teaching materials, with lecturers relying mainly on simple handout; (3) learning tools are used in a fragmented manner, as teaching materials, student worksheets, syllabi, lesson plans, and assessment instruments are not integrated; and (4) practical activities are provided in very limited portions. Under these conditions, prospective teachers tend to depend heavily on lecturers' instructions, resulting in predominantly teacher-centered learning. In addition, evaluation tools in worksheets and handouts are often misaligned with learning indicators and objectives. Therefore, it is necessary to develop integrated instructional tools aligned with curriculum-based learning objectives to enhance science teachers' competence in Earth Science.

The competence of science teachers in teaching Earth Science is likely reflected in students' performance in Earth Science competitions. According to Trianung et al (2024), the result of PISA for Indonesia in 2022 for the science literacy aspect placed in 65 with a score of 383. Thus result are increasing; however, it is not excelent. On the other hand, in the subsequent 18th IESO, four Indonesian students achieved eleven medals, including one gold, four silver, and six bronze medals, demonstrating notable performance at the international level(Clarke 2025). These results indicate that while Indonesian students can achieve respectable outcomes on the international stage, there remains room to strengthen conceptual mastery and higher-order thinking skills through improved instructional support in Earth Science at the teacher education level.

Higher-order thinking skills that need to be developed in Earth Science learning include critical thinking, creativity, problem solving, decision making, and generic science skills(Yosepha et al., 2023). Generic science skills refer to thinking and action skills grounded in scientific knowledge acquired through science learning (Khabibah et al., 2017). Students' who have expertly generic science skill can applying various scientific concepts and problem contexts in inquiry, experimentation, or evidence evaluation (Haviz et al. 2018). According to Brotosiswoyo at Khoiri et al. (2020), Generic science skills essential for planning and conducting inquiry activities include: (1) direct observation, (2) indirect observation, (3) symbolic language, (4) awareness of scale, (5) logical inference, (6) cause–effect relationships, (7) modeling, (8) logical consistency, and (9) concept construction. So, The teachers' incompetence on generic science skills can be impact on the students' low GSS (Pujani et al., 2018; Sudarmin et al., 2018).

In line with generic science skills, Problem-solving ability is a crucial skill in 21st century required to find solutions to problems (Maksimilianus et al., 2022). Problem solving skills can be nurtured by science education as it involves acquiring and organizing information through careful investigation to achieve specific goals (Wahyuni., 2025). It is also considered a cognitive strategy necessary for students in daily life. Field data indicate that university students' generic science and problem-solving skills remain low, as reflected in their Earth Science learning outcomes. Low learning achievement has been associated with weak problem-solving skills (Mahmudi & Kusairi 2019).

Previous studies have identified inquiry-based learning as an instructional model that could foster students' generic science skills and problem-solving abilities (Lin et al., 2021; Razali et al., 2020). Inquiry-based learning is recognized as a model that promotes the development of intelligent, critical, and broad-minded learners (Putra et al., 2018). Syntax of the inquiry-based trains students

to conduct investigations, explain phenomena, identify the core meaning of problems, and solve them through independent scientific procedures(Husnaini & Chen., 2019). However, the implementation of inquiry learning in higher education, particularly in science teacher education programs, often encounters limitations related to the availability and quality of supporting teaching materials (Pujani et al., 2022). The instructional materials currently used in Earth Science teacher education remain systemically limited. Most resources are fragmented, with syllabi, worksheets, laboratory activities, and assessments developed separately rather than as an integrated learning package. They also emphasize theoretical content and routine exercises, while providing limited opportunities for scientific investigation. Furthermore, they lack structured inquiry-based components, such as problem orientation, question formulation, hypothesis development, investigation procedures, data interpretation, and reflection. Consequently, students are not adequately supported in developing generic science skills and problem-solving abilities through authentic inquiry processes. In other hand, Existing handbooks commonly used in universities tend to focus predominantly on content explanations and sets of practice questions, with insufficient integration of essential inquiry components such as problem orientation, question generation, and structured experimental guidance. As a result, the inquiry process is not optimally facilitated, and the potential of this model to empower generic science skills and problem-solving ability remains underutilized.

Based on these limitations, this study develops an inquiry-based Earth Science handbook that integrates learning materials, laboratory activities, and assessment into a coherent instructional package. The novelty of this study lies in embedding structured inquiry components throughout the handbook to systematically cultivate pre-service teachers' generic science skills and problem-solving abilities. Considering the characteristics of inquiry-based learning, the developed handbook aims to cultivate generic science skills and problem-solving abilities in Earth Science. So, this study is conducted under the title Reframing the Earth Science Handbook to Cultivate Pre-Service Teachers' Generic Science Skills and Problem-Solving. The novelty of this study lies not merely in implementing inquiry-based learning but in developing an inquiry-based Earth Science handbook specifically designed to incorporate structured inquiry elements that support the enhancement of students' generic science skills and problem-solving abilities.

The objectives of this study are: (1) to analyze information required to establish empirical and theoretical conditions necessary for designing a draft of Earth Science teaching materials, including literature review and field study. The literature review examines Earth Science content in teacher education curricula, inquiry-based learning procedures, and indicators of generic science skills and problem-solving ability. The field study identifies lecturers' constraints and student characteristics. These findings form the basis for developing teaching materials. (2) to design the draft of Earth Science teaching materials; and (3) to validate the draft, including the syllabus, lesson plans, teaching materials, laboratory worksheets or practicum guides, generic science skills tests, and problem-solving ability tests.

2. Method

This research employed a Research and Development (R&D) approach using the 4D model, which consists of Define, Design, Develop, and Disseminate stages based on Thiagarajan in 1974 (Hariyanto et al., 2022). In this study, only the first three stages as Define, Design, and Develop were conducted, while the Dissemination stage is planned for the subsequent year of the research. The Define stage involved a needs assessment through the collection of relevant information. The Design stage focused on preparing the initial product in the form of a draft of instructional materials. The Develop stage involved refining and validating the developed product. The overall research procedure is presented in Figure 1.

The reframing process was conducted systematically by mapping Earth Science topics to inquiry-based learning syntax and the targeted Generic Science Skills (GSS) and problem-solving indicators. A design matrix was developed to ensure alignment among learning outcomes, Earth Science content, inquiry activities, laboratory investigations, student worksheets, and assessment instruments. Each handbook chapter was organized according to the inquiry phases of problem orientation, question formulation, hypothesis development, investigation, data interpretation, and reflection. This systematic alignment ensured that every learning activity explicitly facilitated the development of Generic Science Skills and problem-solving abilities rather than merely delivering conceptual knowledge.

To operationalize the reframing process, a design alignment matrix was developed to ensure systematic consistency among Earth Science content, inquiry-based learning syntax, Generic Science Skills (GSS), problem-solving indicators, and the instructional components included in the handbook. This matrix served as the primary framework for organizing the learning activities and assessment tasks, ensuring that each topic was explicitly linked to the intended learning outcomes and inquiry process. The alignment matrix is presented in Table 1.

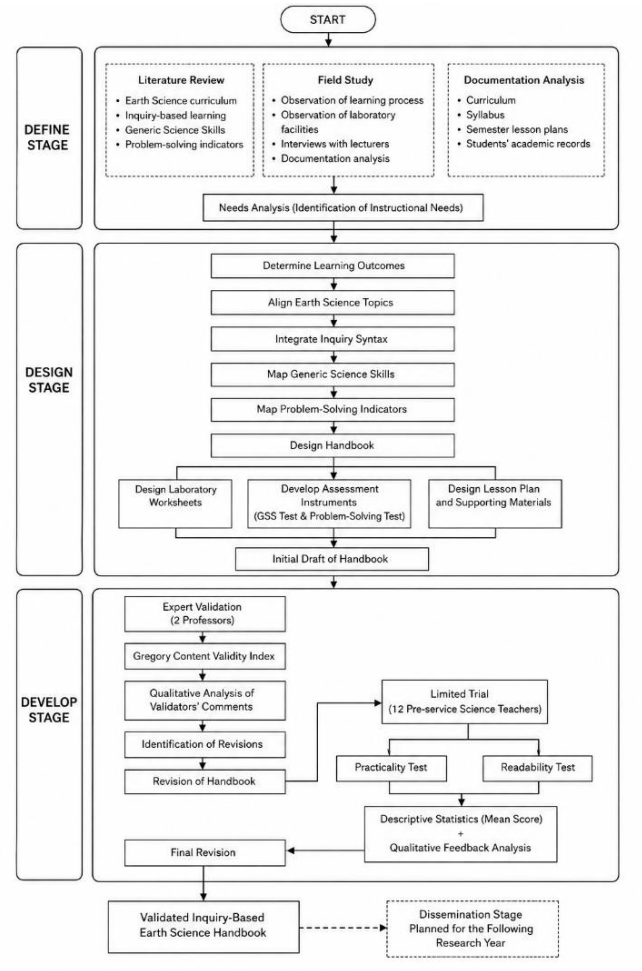


Figure 1. Research Flowchart

Table 1. Alignment Matrix for Reframing the Earth Science Handbook Based on Inquiry Learning, Generic Science Skills, and Problem-Solving Indicators

Earth Science Topic	Inquiry Learning Phase	Generic Science Skills (GSS)	Problem-Solving Indicator	Handbook Component
Earth's Structure	Problem Orientation	Direct Observation	Identifying scientific problems	Contextual phenomenon, guiding questions
Plate Tectonics	Question Formulation	Logical Inference	Formulating hypotheses	Inquiry worksheet
Earthquakes	Investigation	Cause–Effect Relationship	Collecting and analyzing evidence	Laboratory activity
Volcanoes	Data Interpretation	Symbolic Language	Interpreting scientific data	Data analysis exercises
Weather and Climate	Explanation	Concept Construction	Developing solutions	Discussion tasks
Natural Resources	Reflection	Logical Consistency	Evaluating alternative solutions	Reflection questions and case studies

The research subjects included lecturers responsible for teaching the Earth Science course and students of the Undergraduate Science Education Program, Faculty of Mathematics and Natural Sciences, Universitas Pendidikan Ganesha, who were enrolled in the course. The participants

consisted of two expert validators (professors in Earth Science), three lecturer-practitioners teaching the course, and twelve prospective science teacher students.

This study employed a triangulated data collection approach to ensure the credibility of the needs analysis. Objectivity was maintained by cross-validating findings across three distinct sources: classroom observations of the instructional process, limited interviews with lecturers to identify pedagogical constraints, and documentation analysis of the curriculum and students' academic records. This rigorous cross-verification process was specifically designed to minimize individual observer bias and provide a comprehensive empirical foundation for the handbook's design. Data were collected through observation, interviews, and documentation. Observations were conducted on the implementation of the learning process and the available Earth Science laboratory facilities. Limited interviews were conducted with course lecturers to identify instructional challenges. Documentation methods were used to examine supporting data such as the curriculum, syllabus, semester lesson plans, and students' academic records. The findings from the literature review and field study formed the basis for designing the draft teaching materials to be validated by experts.

Furthermore, to ensure objectivity and address potential bias during field observations and interviews, the researchers implemented investigator triangulation by involving multiple observers. A standardized observation rubric was utilized, and member checking was conducted by verifying interview summaries with the participating lecturers to ensure the findings accurately reflected the instructional conditions and challenges (responses to reviewer B).

Quantitative data from expert judgments were analyzed using Gregory's Content Validity Index to determine the content validity of the developed handbook and its supporting instruments. These recommendations were incorporated into the revised handbook before readability testing. Quantitative data from expert judgment were analyzed using Gregory's content validity index as shown at Table 2 (Diana & Rampeng 2023).

Table 2. Gregory Content Validity Index Criteria

Gregory Index Value	Validity Category	Interpretation
0.80 – 1.00	Very High Validity	The handbook is highly valid and appropriate for use without major revision
0.60 – 0.79	High Validity	The handbook is valid with minor revisions
0.40 – 0.59	Moderate Validity	The handbook requires revision before use
0.20 – 0.39	Low Validity	The handbook needs major revision
0.00 – 0.19	Very Low Validity	The handbook is not appropriate for use

The content validity assessment was conducted by two professors with recognized expertise in Earth Science and science education. Although the number of expert validators was limited, their extensive academic experience and subject-matter expertise provided authoritative judgments regarding the relevance, accuracy, and consistency of the handbook components. Gregory's Content Validity Index is specifically designed for content validation involving two expert judges, making it appropriate for this study. The experts also provided qualitative recommendations, which were systematically incorporated into the revised handbook before the readability and practicality evaluations.

Then, Practicality and readability data were analyzed using descriptive statistics interpreted according to the predefined criteria. Furthermore, the practicality and readability scores were analyzed using mean values and categorized according to the criteria presented in Table 3 (Sarini & Selamet., 2019).

Table 3. Categorization of Mean Scores for Practicality and Readability Tests

Mean Score Range	Category	Interpretation
3.25 – 4.00	Very High	The handbook is very practical / very easy to read and understand
2.50 – 3.24	High	The handbook is practical/easy to read
1.75 – 2.49	Low	The handbook is less practical / less readable
1.00 – 1.74	Very Low	The handbook is impractical/difficult to read

The practicality and readability evaluation involved 12 pre-service science teachers who had completed the Earth Science course. This sample size was considered appropriate for the limited trial

stage of the Research and Development (R&D) process, as its primary purpose was to identify usability issues, assess the clarity of content and instructions, and obtain representative user feedback for product refinement before large-scale implementation. In addition, qualitative comments from the participants were analyzed to identify aspects requiring revision and to support the interpretation of the quantitative findings

The validity, practicality, and readability data were analyzed obtained from questionnaire instruments administered to research subjects. To provide a more comprehensive evaluation, quantitative findings were complemented with qualitative analysis of validators' comments and suggestions. The qualitative analysis identified strengths, weaknesses, and aspects requiring revision, which were then incorporated into the refinement of the handbook, student worksheets, Generic Science Skills test, and problem-solving ability test.

3. Results and Discussion

3.1. Define Stage

At this stage, identification was conducted to determine the fundamental components that require reframing in the development of the Earth Science handbook, based on findings from the preliminary study. The identification process included a literature review, direct observation, curriculum analysis, analysis of Earth Science practicum guidelines, laboratory facility analysis, and analysis of student characteristics.

3.1.1. Results of Literature Review

The literature review was conducted to define the dependent variables and the instructional model used as the learning setting in this study. The dependent variables include generic science skills and problem-solving ability, while the instructional model adopted is inquiry-based learning. Generic science skills are abilities that can be applied to understand various scientific concepts and solve problems in science (Brotosiswoyo., 2000 at Haviz et al., 2018). These skills are broadly utilized in scientific work. Many generic skills can be developed through laboratory activities, such as decision-making, problem-solving, communication, teamwork, and higher-order reasoning (Jääskelä et al., 2018). According to McDermott in Pujani et al (2018) , generic science skills essential in planning and conducting inquiry activities include: (1) direct observation, (2) indirect observation, (3) symbolic language, (4) awareness of scale, (5) logical inference, (6) cause–effect relationships, (7) modeling, (8) logical consistency, and (9) concept construction. Problem solving refers to the effort of individuals or groups to find solutions based on prior understanding in response to unfamiliar situations (Rahmah et al., 2021). Problem-solving ability is the capacity of individuals to resolve problems effectively. According to Heller (cited in Tanjung et al., 2024) describe five stages of problem solving: (1) focusing the problem, (2) describing the physics concepts involved, (3) planning the solution, (4) executing the plan, and (5) evaluating the solution. Inquiry is a general human process for seeking and understanding information. Apriyani, Ramalis, and Suwarma (2019) defines inquiry strategy as a sequence of learning activities that maximally engage students' abilities to investigate systematically, critically, logically, and analytically, enabling them to formulate their own findings confidently. The stages of inquiry-based learning include: (1) formulating problems, (2) proposing hypotheses, (3) designing and conducting experiments, (4) collecting and processing data, (5) interpreting results and discussion, and (6) drawing conclusions

Previous studies consistently indicate that inquiry-based learning is among the most effective instructional approaches for developing these competencies because it actively involves students in formulating problems, designing investigations, collecting evidence, interpreting data, and constructing scientific explanations. Consequently, inquiry-based learning was selected as the pedagogical foundation of the developed handbook. This theoretical synthesis suggests that effective Earth Science instructional materials should not merely present scientific concepts but should also facilitate structured inquiry processes that encourage students to construct knowledge independently through authentic scientific investigation. Although the Earth Science course covers the fundamental domains required for prospective science teachers, the analysis indicates a misalignment between the intended learning outcomes and the instructional activities. Most learning outcomes emphasize conceptual understanding, whereas opportunities to develop inquiry competence, Generic Science Skills (GSS), and problem-solving ability remain limited. This finding

suggests that curriculum implementation still prioritizes content acquisition over scientific inquiry, highlighting the need for instructional materials that integrate conceptual knowledge with inquiry-oriented learning experiences.

3.1.2. Results of Field Study

Observations revealed several issues in the current implementation of Earth Science instruction: (1) Instruction predominantly uses presentation and discussion methods, with very limited laboratory activities; (2) Classroom learning is insufficiently connected to students' daily experiences, making learning less meaningful; (3) Students are rarely guided to discover essential Earth Science concepts through experiential learning independently; (4) Introductory Earth Science teaching materials are not yet available; students generally rely on various external references; (5) Practical work is seldom conducted due to limited laboratory equipment. Based on these findings, it is necessary to develop an Introductory Earth Science handbook integrated with practicum guidelines to ensure a more systematic learning process.

Interviews with lecturers further indicated that students generally depended on lecturers' explanations rather than constructing scientific understanding independently. Existing instructional materials mainly consisted of fragmented lecture notes and external references, without integrated practicum guidance or inquiry-oriented learning activities. Consequently, students had limited opportunities to investigate scientific phenomena, formulate hypotheses, analyze evidence, and develop scientific reasoning.

These findings indicate that the current instructional system emphasizes conceptual knowledge acquisition rather than inquiry-oriented learning. Such conditions are unlikely to optimally foster Generic Science Skills and problem-solving ability, both of which require repeated engagement in scientific investigation and reflective reasoning. Therefore, the development of an integrated inquiry-based handbook becomes an essential instructional intervention rather than merely an additional learning resource.

3.1.3. Curriculum Analysis of Earth Science Course

The curriculum used in the Undergraduate Science Education Program is the 2024 competency-based curriculum aligned with the Indonesian National Qualification Framework (KKNI). The Earth Science course is offered in the third semester. The scope of Earth Science content is presented in Table 4.

Table 4. Scope of Earth Science Course Content in the Undergraduate Science Education Program

No.	Learning Outcome Indicators	Main Topics
1	Explain the shape, size, and motion of the Earth; Describe the layers of the Earth and their composition; Analyze rock formation processes in the lithosphere; Explain the rock cycle; Describe the formation of rocks and minerals in nature	Structure and Layers of the Earth; Lithosphere
2	Identify types of geological forces; Explain the influence of endogenic forces on landforms; Describe the concept of plate movement; Explain the impacts of plate movement; Identify active zones based on plate tectonics; Explain volcanism and its impacts; Explain earthquakes	Lithosphere and Geological Forces; Endogenic Processes
3	Analyze the effects of exogenic forces on landforms; Explain weathering, erosion, and deposition processes and their geological impacts; Conduct practicum on rocks, minerals, erosion, and weathering	Exogenic Processes
4	Define the hydrological cycle; Explain small, medium, and large hydrological cycles; Differentiate types of hydrological cycles; Describe the importance of the hydrological cycle for life; Differentiate inland and marine waters; Identify causes of ocean waves; Explain salt composition in oceans; Describe factors influencing groundwater infiltration	Hydrology
5	Identify the structure of the atmosphere; Explain physical characteristics of each atmospheric layer; Describe the benefits of the atmosphere for life; Explain global atmospheric circulation; Differentiate land and sea breezes; Differentiate weather and climate; Identify factors affecting weather and climate	Atmosphere

Based on the curriculum structure in Table 3, the implementation of the Earth Science course at the Science Education Bachelor's Degree only carries a weight of 2 credit units, with one credit equivalent to 50 minutes of face-to-face theoretical instruction. Despite the relatively small credit load, practical activities need to be strategically integrated to equip students with essential

foundational skills in learning Earth Science. These activities are crucial not only for conceptual mastery but also for the development of skills, scientific attitudes, generic science skills, and problem-solving abilities. The Earth Science content taught covers fundamental Earth Science concepts; however, the formulation of learning indicators has not yet been oriented toward the development of higher-order thinking skills (HOTS).

3.1.4. Analysis of Earth Science Practicum Guidelines

Observations revealed several findings regarding the availability of Earth Science practicum guidelines: (1) Almost all respondents stated that practical activities were rarely conducted during Earth Science instruction in the Undergraduate Science Education Program due to the absence of comprehensive practicum guidelines; (2) Laboratory facilities are shared with other study programs within the faculty, resulting in limited access and insufficient time allocation for practicum activities; (3) Some practicum guidelines exist; however, they are limited to brief tool manuals and short procedural instructions. These guidelines lack essential components necessary for structured scientific investigation. Based on these findings, the analysis of existing practicum guidelines identified several important limitations. First, practical activities were rarely implemented because no comprehensive practicum handbook was available. Second, the available practicum manuals primarily contained procedural instructions without incorporating scientific inquiry components such as problem identification, hypothesis formulation, data interpretation, or reflective discussion.

As a result, laboratory activities functioned primarily as verification exercises rather than opportunities for scientific investigation. This finding suggests that existing practicum materials have not yet supported the development of Generic Science Skills and higher-order thinking. Therefore, the newly developed handbook integrates laboratory worksheets directly into each chapter to ensure that practical activities become an integral component of inquiry-based learning rather than supplementary exercises.

3.1.5. Analysis of Earth Science Laboratory Facilities

In addition to the lack of practicum guidelines, Earth Science laboratory equipment is also insufficient. As the study program is relatively new, laboratory usage is still shared with other programs. Laboratory observations revealed that Earth Science facilities remain limited because laboratory resources are shared among several study programs. This limitation reduces students' opportunities to conduct practical investigations regularly. The limited availability of equipment can be addressed by developing instructional teaching aids from simple and locally available materials. However, overall laboratory support facilities for the Earth Science practicum at the teacher education institution in Singaraja remain inadequate.

However, rather than treating this condition solely as a constraint, the handbook was designed to accommodate simple investigations using inexpensive and locally available materials. Such an approach increases the feasibility of inquiry implementation despite laboratory limitations while simultaneously encouraging students to develop creativity and scientific reasoning through authentic problem-solving activities.

3.1.6. Analysis of Student Characteristics

Observations of students in the Undergraduate Science Education Program revealed several characteristics: (1) Students generally demonstrate moderate intellectual ability; thus, their capacity for abstract thinking in science concepts remains relatively limited; (2) Student participation in classroom learning is relatively low, as many students tend to wait for lecturer instructions and are not yet fully active in class discussions; (3) Students are rarely confronted with real-life problem situations, leading to a tendency toward rote learning rather than meaningful conceptual understanding. These characteristics imply that the existing learning environment still promotes passive knowledge acquisition rather than active knowledge construction. Since Generic Science Skills and problem-solving ability develop primarily through repeated inquiry experiences, instructional materials should provide structured opportunities for observation, investigation, discussion, and reflection.

Based on these findings, it is necessary to develop a comprehensive handbook for the Earth Science course, including the instructional materials, inquiry phase, semester lesson plans, and Earth

Science practicum guidelines. Consequently, student characteristics identified during the Define stage became one of the primary considerations in designing the inquiry-based handbook. The reframing of a Earth Science handbook using an inquiry -based approach is expected to enhance students' generic science skills and problem-solving abilities.

3.2. Design Stage

Based on the instructional needs identified during the Define stage, the Design stage focused on constructing an inquiry-based Earth Science handbook that systematically integrates Earth Science content, inquiry learning syntax, Generic Science Skills (GSS), and problem-solving indicators. Rather than simply reorganizing existing learning materials, the handbook was developed through a reframing process in which every chapter was redesigned to facilitate conceptual understanding alongside scientific inquiry.

The handbook consists of ten chapters covering Earth's structure, lithosphere, hydrosphere, atmosphere, and Earth-related natural phenomena, which were ten chapters is (1) Earth's Shape and the History of Earth Formation; (2) Rocks and Minerals; (3) Endogenic Processes (Tectonism and Earthquakes); (4) Endogenic Processes (Volcanism); (5) Exogenic Processes; (6) Hydrological Cycle and Inland Waters; (7) Marine Waters; (8) Atmospheric Structure and Clouds; (9) Weather and Climate; and (10) Optical Phenomena in the Atmosphere. In addition, assessments were designed based students' problem-solving ability and generic science skills in the context of Earth Science. A simplified layout of the Earth Science handbook is presented in Figure 2.



Figure 2. The Geosains Handbook Interface

Furthermore, based on the preliminary analysis conducted in the define stage, the developed Introductory Earth Science teaching materials were complemented with practicum guidelines to facilitate inquiry skills, as well as assessment instruments to measure students' problem-solving ability and generic science skills. Then, the inquiry-based learning syntax is explicitly embedded within the structure of each chapter in the developed Earth Science handbook. Each topic begins with a problem-oriented section that presents contextual Earth Science phenomena to stimulate curiosity and activate prior knowledge. This is followed by a question-generation component, where students are guided to formulate investigable questions and tentative hypotheses. The handbook then provides structured experimental or investigative procedures through practicum guidelines, enabling students to collect and analyze data. Subsequent sections guide students in interpreting findings, linking empirical evidence to scientific concepts, and engaging in reflective discussion. Finally, each chapter concludes with concept reinforcement and evaluation tasks, ensuring that students synthesize their understanding and apply it to problem-solving situations. To ensure systematic implementation of the reframing process, an alignment matrix was developed by mapping each Earth Science topic to the corresponding inquiry learning phase, targeted Generic Science Skills,

and problem-solving indicators. This matrix functioned as the primary instructional blueprint, ensuring consistency among learning objectives, instructional activities, laboratory investigations, and assessment instruments.

Every inquiry phase that shown at table 1 has serves a distinct pedagogical function. The problem-orientation phase stimulates curiosity through authentic Earth Science phenomena, whereas question formulation encourages logical reasoning and hypothesis generation. Investigation activities promote observation, experimentation, and evidence collection, while data interpretation develops analytical thinking and cause-and-effect reasoning. Finally, the reflection phase facilitates concept construction and evaluation of alternative solutions. This systematic alignment ensures that students continuously engage in inquiry processes throughout the learning sequence rather than treating inquiry as an isolated classroom activity. Compared with conventional Earth Science textbooks that primarily emphasize conceptual explanation and routine exercises, the developed handbook embeds inquiry syntax within every instructional component. Consequently, students are expected not only to acquire conceptual understanding but also to develop transferable Generic Science Skills and problem-solving competencies required for science teaching and lifelong learning.

3.3. Develop Stage

The Develop stage focused on evaluating and refining the initial Earth Science handbook through expert validation, practitioner evaluation, and student readability testing. The evaluation was designed not only to determine whether the instructional package met predefined validity, practicality, and readability criteria, but also to identify specific aspects requiring refinement. Accordingly, quantitative scores were interpreted together with qualitative feedback to determine the instructional strengths and remaining weaknesses of the developed handbook.

3.3.1. Validity Test Results

The initial draft of the Earth Science handbook, student worksheets, and assessment instruments was evaluated by two expert professors with expertise in Earth Science and science education. The validation covered the teaching materials, student worksheets, Generic Science Skills (GSS) test, and problem-solving ability test. Gregory's Content Validity Index was used to determine the degree of agreement between the two experts. The recapitulation of expert judgment results is presented in Table 5.

Table 5. Recapitulation of Expert Judgment Using Gregory's Content Validity Index

teaching materials (12 points)		Expert I		Gregory's Index
		Disagree (sore 1-2)	Agree (score 3-4)	
Expert II	Disagree (score 1-2)	(A) (0)	(B) (0)	1,0
	Agree (Score 3-4)	(C) (0)	(D) (12)	
Worksheet (50 points)		Expert I		
		Disagree (sore 1-2)	Agree (score 3-4)	
Expert II	Disagree (score 1-2)	(A) (0)	(B) (0)	1,0
	Agree (Score 3-4)	(C) (0)	(D) (50)	
Assessment (26 points)		Expert I		
		Disagree (sore 1-2)	Agree (score 3-4)	
Expert II	Disagree (score 1-2)	(A) (0)	(B) (0)	1,0
	Agree (Score 3-4)	(C) (0)	(D) (26)	

Note: A = Both experts disagree; B = Expert I agrees, Expert II disagrees; C = Expert I disagrees, Expert II agrees; D= Both experts agree

Based on Table 5, the results of expert validation indicate that all assessed aspects obtained a Gregory Index score of 1.00. This finding demonstrates that the developed teaching materials meet the criteria of very high validity. The Gregory Index values for each aspect consistently fall within the very high content validity, indicating strong agreement among experts regarding the appropriateness of the materials. Importantly, this result should not be interpreted merely as evidence that the handbook is "valid"; rather, it indicates that the essential content and structural

components of the instructional package were considered sufficiently aligned with the intended learning objectives. In addition to the quantitative evaluation using Gregory's Index, expert validators also provided qualitative feedback to be addressed in the revision process. These suggestions were aimed at improving the Earth Science teaching materials, student worksheets, the generic science skills (KGS) test, and the problem-solving ability (KPM) test. A summary of the recommended revisions for the developed teaching materials and assessment instruments is presented in Table 6.

Table 6. Revisions of the Teaching Materials Based on Expert Feedback

Expert Feedback	Condition Before Revision	Revisions Made
Learning outcome indicators should consistently use operational verbs at varying cognitive levels	Several learning indicators did not use operational verbs at different cognitive levels	Learning indicators were revised to use operational verbs at appropriate and varied cognitive levels
Each chapter should include practice questions or problem tasks to support action using GS and PS tests	No practice questions or problem-solving tasks were provided at the end of each chapter	Practice questions and problem-solving tasks using GS and PS tests were added at the end of each chapter
Many words were written without proper spacing, and spacing was inconsistent	Errors in spacing and word separation were found across chapters	Spelling and spacing were checked and corrected throughout the material
All tables and figures should be numbered and referenced in the text	Tables and figures were not properly numbered or cited in the text	Proper numbering and in-text referencing of tables and figures were added
All displayed figures should include sources	Several figures lacked source citations	Sources were added for all figures used
Errors were found in the reference list	The reference list contained writing errors	The reference list was reviewed and corrected
Inconsistencies were found between learning indicators in the materials and those in KGS and KPM tests (differences in operational verbs)	Some discrepancies existed between instructional indicators and test indicators	Indicators in teaching materials and KGS/KPM tests were aligned and made consistent
Instructions for answering test questions were not provided	Test instructions were missing	Clear instructions for answering the test were added
Questions should include data or information to be analyzed rather than relying on memorization	Some test items lacked analyzable data or information	Test items were revised to include data or information requiring analysis
A scoring rubric should be provided at the beginning to clarify assessment criteria	No scoring rubric was included	A scoring rubric was added to the front section of the material

The qualitative feedback provided by the experts further contributed to the interpretation of the quantitative results. Although the Gregory Index reached the maximum value, the experts identified several aspects requiring refinement. Most recommendations concerned the pedagogical and assessment alignment of the handbook rather than fundamental inaccuracies in the Earth Science content. This distinction is important because it indicates that the initial draft was conceptually acceptable but still required refinement to improve its instructional coherence and capacity to support inquiry-based learning. For example, the experts identified inconsistencies between learning indicators in the handbook and those used in the GSS and problem-solving tests. They also recommended adding analytical information to test items, practice questions at the end of each chapter, clearer test instructions, and a scoring rubric. These recommendations indicate that validity involved more than scientific correctness; the experts also examined whether the instructional components and assessment instruments worked coherently toward the targeted competencies.

Table 6 reveals an important characteristic of the development process. The recommendations were concentrated on three major dimensions: instructional alignment, inquiry-oriented assessment, and technical presentation. The first two dimensions are particularly relevant to the reframing objective because they strengthen the connection between learning activities and the targeted GSS and problem-solving competencies. The addition of analytical information to test items, for instance, shifts assessment from simple recall toward evidence-based reasoning. Similarly, aligning learning indicators with the GSS and problem-solving tests increases coherence between what students are expected to learn and what they are subsequently asked to demonstrate. Thus, the maximum Gregory Index should be interpreted together with the qualitative revision evidence. While the quantitative assessment demonstrated strong agreement between experts, the qualitative

findings revealed that high content validity did not imply that the first draft was already optimal in pedagogical execution. The revision process therefore strengthened the instructional coherence of the handbook before it proceeded to practitioner and student evaluation.

3.3.2. Practicality Test Result

After completing expert validation and subsequent revisions, the draft teaching materials proceeded to the practicality testing stage conducted by Earth Science lecturer-practitioners. The results of the practicality test are presented in Table 7.

Table 7. Results of the Practicality Test by Lecturer-Practitioners

Practitioner	Mean Score	Category
Practitioner 1	3.7	Very Practical
Practitioner 2	3.7	Very Practical
Practitioner 3	3.8	Very Practical
Average	3.73	Very Practical

Based on Table 7, the overall mean score of the practicality test conducted by lecturer-practitioners was 3.73, which falls within the very practical category. These results indicate that the developed teaching materials are easy to use, feasible to implement in classroom settings, and suitable to support Earth Science instruction. Furthermore, no suggestions for revision were provided by the practitioners, indicating a high level of acceptance of the developed materials.

The practicality test results indicate that the inquiry-based Earth Science handbook is highly feasible for use in Earth Science instruction. The high mean score reflects that the handbook is easy to implement and supports lecturers in organizing learning activities effectively. The structured integration of inquiry steps, practicum guidance, and assessment components contributes to the smooth application of the handbook in classroom settings. Overall, these findings confirm that the developed inquiry-based Earth Science handbook demonstrates a high level of practicality in supporting meaningful Earth Science learning.

However, the practicality result should be interpreted within the scope of the study. The assessment represents perceived practicality by lecturer-practitioners, rather than evidence of actual implementation effectiveness in a full classroom setting. Therefore, the result supports the feasibility of the handbook for subsequent implementation but does not yet establish whether lecturers can implement all inquiry activities effectively under authentic classroom and laboratory conditions.

3.3.3. Readability Test Result

The readability test was conducted to obtain feedback from students regarding the developed Earth Science teaching materials. This test involved ten third-semester students of the Undergraduate Science Education Program in the 2025/2026 academic year. Data were collected using a questionnaire consisting of nine assessment items. The results of the readability test are presented in Table 8.

Table 8. Recapitulation of Readability Test Results

No.	Statement	Mean Score
1	Appropriateness of the cover design with the content of the teaching materials	3.7
2	Appropriateness of font type and size used	3.3
3	Relevance of images to the learning content	3.3
4	Appropriateness of color usage in the teaching materials	3.7
5	The teaching materials make me feel motivated and enjoy learning Earth Science	4.0
6	The explanation of the content helps me understand concepts more easily	3.5
7	Problem-oriented presentation facilitates understanding of Earth Science concepts	3.8
8	The language used in the teaching materials is clear and easy to understand	4.0
9	Sentences in the teaching materials are easy to comprehend	3.6
Average		3.66
Category		Very Readable

Based on the data presented in Table 8, the overall mean score of the readability test conducted by students was 3.66, which falls within the very readable category. However, the item-level results reveal meaningful variation that is obscured by the overall mean score. The highest ratings were obtained for language clarity and students' motivation and enjoyment in learning Earth Science (both 4.00), indicating that the handbook successfully communicated the content in accessible language and presented the material in a manner that supported students' learning interest. This finding is particularly relevant to the reframing process because the handbook was designed to present Earth Science concepts through contextual and problem-oriented learning experiences rather than through theoretical explanations alone. Overall, the item-level pattern demonstrates that the high readability score was not uniform across all dimensions. The 0.70-point difference between the highest and lowest item scores indicates that aggregating the results into a single mean would conceal specific areas requiring improvement. Thus, the readability analysis provides more than evidence of general acceptability, it identifies concrete design features that can be refined before large-scale implementation.

3.4. Discussion of The Development Result

Based on the identified findings, it was deemed necessary to develop Introductory Earth Science teaching materials equipped with practicum guidelines to facilitate inquiry skills, as well as assessment instruments to measure students' problem-solving ability and generic science skills. The development of inquiry-based teaching materials is expected to support students in actively constructing knowledge and, consequently, enhancing both their problem-solving skills and generic science skills in Earth Science learning.

This study focused on analyzing the characteristics, validity, practicality, and readability of the developed Earth Science teaching materials. The resulting materials were subsequently subjected to expert validation, leading to the production of a second draft of the instructional package. The validation process employed expert judgment instruments consisting of validation sheets for teaching materials, student worksheets (LKM), generic science skills tests, and problem-solving ability tests. The validity, practicality, and readability results provide convergent evidence that the developed inquiry-based Earth Science handbook has reached an appropriate level of preliminary quality for subsequent effectiveness testing. The Gregory Index of 1.00 demonstrates strong agreement between the two expert validators regarding the relevance and appropriateness of the instructional components. This finding is consistent with previous research showing that instructional materials developed through systematic curriculum analysis and alignment with learning objectives tend to achieve high content validity (Pujani et al., 2022). However, the qualitative feedback in the present study provides an additional indication that high content validity does not necessarily mean that the initial product is fully optimized pedagogically. The experts still identified inconsistencies between learning indicators and assessment instruments, insufficient analytical tasks, and the need for clearer assessment procedures. This finding reinforces the importance of formative expert evaluation in ensuring not only content accuracy but also coherence among learning objectives, instructional activities, and assessment.

The high practicality result indicates that the handbook can be feasibly used by lecturer-practitioners. This finding is in line with research on inquiry-based instructional materials showing that structured learning resources can facilitate lecturers in organizing investigation-oriented activities and reduce students' dependence on direct lecturer explanations (Lin et al., 2021; Pujani et al., 2025). The relatively consistent scores among the three practitioners in the present study also suggest that the practicality of the handbook was not dependent on the perception of a single evaluator. The integration of instructional content, practicum guidelines, inquiry activities, and assessment within one learning package may have contributed to this consistency by providing lecturers with a clearer instructional sequence.

The high readability result is also consistent with previous findings that contextualized and inquiry-oriented learning materials can improve students' engagement with scientific concepts (Herayanti & Sukroyanti., 2022). However, the item-level analysis provides a more nuanced interpretation. Students gave the highest ratings to language clarity and learning motivation (both 4.00), while font type and size and image relevance received the lowest ratings (both 3.30). This pattern indicates that the strength of the handbook lies primarily in its linguistic and instructional accessibility, whereas some aspects of visual presentation require further refinement. The relatively

high score for problem-oriented presentation is particularly important because it supports the design rationale of the reframing process: presenting Earth Science concepts through contextual problems appears to make abstract content more accessible to learners.

The exceptional readability score stems from a synergistic combination of design elements. Specifically, the integration of contextual images helps ground abstract geological concepts into concrete visual representations, while the communicative language style mirrors the natural dialogue of the classroom. Most importantly, the inquiry structure itself, starting with real-world phenomena and creates a 'need-to-know' environment. This pedagogical narrative makes the content more intuitive and accessible, as students are motivated to read further to find solutions to the identified problems.

The combined findings also support the theoretical rationale for integrating inquiry-based learning into Earth Science instructional materials. Inquiry learning requires students to engage in questioning, investigation, evidence interpretation, and explanation rather than merely receiving scientific information. Such processes have been reported to support the development of higher-order thinking, Generic Science Skills, and problem-solving abilities (Faradilla et al., 2018; Herayanti & Sukroyanti, 2022; Pujani et al., 2025). In the present study, these principles were operationalized through the integration of problem orientation, question formulation, investigation, data analysis, interpretation, and reflection into the handbook. Thus, the contribution of the present study is not simply the development of another Earth Science textbook, but the reframing of Earth Science instructional materials into an integrated inquiry-based learning resource specifically designed to support Generic Science Skills and problem-solving ability.

4. Conclusion

Based on the research objectives and the findings discussed above, it can be concluded that the define stage identified the importance of developing Earth Science teaching materials for undergraduate students through literature review and field studies. The Earth Science Handbook developed in this study is characterized by the inclusion of chapter titles, learning indicators, problem orientations, content explanations, summaries, and reference lists. In addition, student worksheets were designed separately to effectively facilitate students' inquiry skills during the learning process.

Expert validation results indicated that the developed Earth Science Handbook met both content validity and construct validity criteria, with a Gregory Index value of 1.00, categorized as very valid. The practicality test results showed an average score of 3.73, classified as very practical, while the readability test yielded an average score of 3.66, categorized as very readable. These findings demonstrate that the developed teaching materials are feasible and ready to be continued to the effectiveness testing stage through limited-scale implementation. Furthermore, the developed Earth Science teaching materials are highly needed in the Undergraduate Science Education Program, particularly for students enrolled in the Earth Science course

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Data Availability

The datasets generated during and/ or analysed during the current study are available from the corresponding author on reasonable request.

Declaration on AI Use

The authors declare that no artificial intelligence (AI) or AI-assisted tools were used in the preparation of this manuscript.

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