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Determining Learning Activities to Promote Scientific Reasoning in Science Learning: A Literature Review

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ABSTRACT

Objective: The objective of this study is to analyze learning activities in science learning that can promote scientific reasoning skills and provide the best way to teach it. **Method:** The method used is a literature review analyzing 20 articles indexed by the Scopus database from 2017 – 2022. There are 200 articles about teaching scientific reasoning in the Scopus database, and 20 articles that focused on science learning were selected. The 20 articles then analyzed the domain of scientific reasoning and learning activities to train it. **Results:** The results showed that science learning interventions in practicing scientific reasoning can be carried out starting from secondary to higher education levels. The learning interventions can be designed in face-to-face learning by integrating social science phenomena/cases, conducting guided investigations assisted by modules, and implementing argument-based learning or online learning using mobile apps/online simulations. There is a tendency that investigative activities are the most widely used intervention to promote scientific reasoning skills in science learning. **Novelty:** This study can provide an overview of science learning activities that promote scientific reasoning so that teachers can design the most appropriate learning activities to train students' scientific reasoning.

INTRODUCTION

Scientific reasoning is one of the aspects that can be taught within science learning. It considers one of the provisions for facing the global economy in the 21st century (Bao et al., 2018). Scientific reasoning is the cognitive ability to understand and evaluate scientific information. This process involves understanding and evaluating theory, formulating hypotheses, and solving problems through inquiry. Scientific reasoning skills include the ability to identify scientific problems, formulate problems and hypotheses, predict the possibility behind phenomena, look for evidence through modeling and experiments, as well as communicate and evaluate the concepts (Hartmann et al., 2015).

Scientific reasoning is included in the final stage of developmental cognitive abilities. According to Piaget's theory of cognitive development, this stage refers to formal operations, when children can make reasons more abstractly and logically by looking for links between concepts, analyzing problems scientifically, and searching and evaluating evidence to support or reject a hypothesis (Arends, 2012). Scientific reasoning is highly correlated with children's cognitive abilities in evaluating and developing hypotheses, especially about how phenomena occurred (Zulkipli et al., 2019). Therefore, students with scientific reasoning abilities can apply scientific concepts to assist them in dealing with problems and planning investigations to solve scientific problems in real life (Zhou et al., 2021).

Scientific reasoning is essential for students. Vo & Csapo (2023) stated that scientific reasoning significantly affected learning achievement, including science. However, the profile of students' scientific reasoning skills is still low (Rimadani et al., 2017; Khoirina

et al., 2018; Yediarani et al., 2019; Suryadi et al., 2020). Scientific reasoning abilities are still at the lowest levels in each domain. In addition, low scientific reasoning skills are shown from the results of the PISA study. PISA's questions present the context of problem-solving and decision-making in natural phenomena (Wasis et al., 2017). In 2018, Indonesia obtained a score of 396 in the science domain, which is lower than the OECD average score of 489. This proves that the scientific reasoning ability of Indonesian students still needs to improve. So, teaching scientific reasoning skills through science learning is essential.

Scientific reasoning can be trained during science learning. Janssen et al. (2019) stated that one way to train scientific reasoning is through intervention in the form of pedagogic content. Science learning can be designed in activities that can train students to analyze and evaluate information and develop reasoning abilities (Engelmann et al., 2014). Patoding et al. (2023) stated that scientific reasoning could be trained during. This is also supported by several studies showing the form of various activities in science learning that can be trained in scientific reasoning. This study aims to analyze learning activities in science learning that can promote scientific reasoning skills and provide the best way to teach it. So that teachers can design and implement appropriate learning activities to train students' scientific reasoning skills in science learning.

RESEARCH METHOD

This literature study aims to analyze science learning activities that can be trained in scientific reasoning skills. This research was conducted by analyzing articles indexed by the Scopus database in 2017 – 2022. The keyword used to find articles to be reviewed "scientific reasoning," and 200 articles were obtained. Then, 20 articles related to science learning were selected. The steps in conducting a literature review were adapted from Sukma & Priatna (2021). They consisted of five steps which are (1) identifying articles related to science learning activities to train scientific reasoning, (2) analyzing the domain of scientific reasoning and training, (3) analyzing activities in science learning to train scientific reasoning, (4) making conclusions, and (5) determining recommendations of learning activities to train student's scientific reasoning in science learning. These steps are presented in a flowchart in **Figure 1**.

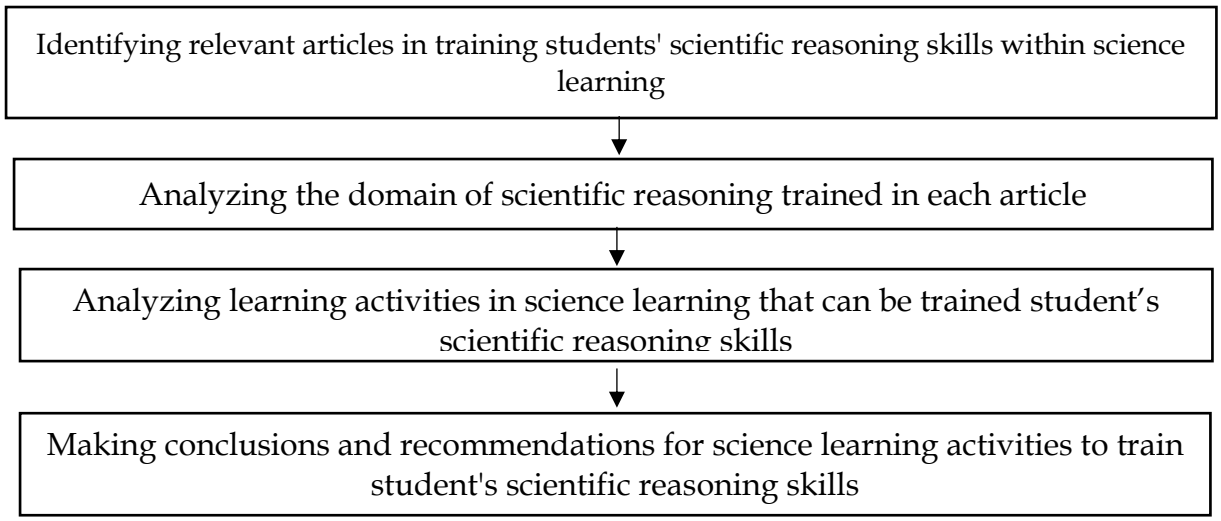

Figure 1. Flowchart research on the science learning activities to train students' scientific reasoning skills.

RESULTS AND DISCUSSION

Results

The analysis of 20 articles related to science learning activities to train scientific reasoning skills was conducted in three aspects: scientific reasoning, learning activities, and findings. The results of the analysis are presented in **Table 1.**

Table 1. The literature review of science learning activities training scientific reasoning skills between 2019-2022.

Author, Year	The Domain of Scientific Reasoning	Learning Activities in Training Scientific Reasoning	Findings
Gohner & Krell, 2022	● Exploration and forming perceptions of phenomena ● Making analogies and developing explanations ● Making predictions based on deduction results	Applying a black box setting that represents authentic scientific phenomena and is rich in content is then investigated through the scientific method to find conceptual understanding. The black box setting was used in the water flow concept.	The black box set can describe the dimensions of scientific reasoning carried out by science teacher candidates in completing assignments in the form of scientific modeling.
Rogele et al., 2022	Scientific investigations include: ● designing experiments ● analyzing data ● creating ideas for problem-solving	Applying project-based citizen science in birding activities. Participants were tasked to observe and identify the bird species during bird watching.	There has been increased knowledge about birds, commitment to birding, and scientific reasoning skills.
Jansong et al., 2022	● Ability to make claims based on facts ● Ability to judge the credibility of information ● Ability to make arguments and ideas from different points of view	Presenting social science issues on the topic of the immune system. The issues used are using vaccines, herbal medicines, PrEP, and PEP for medical purposes and the prohibition of LGBT.	Using social science issues in science learning can improve scientific reasoning skills by 50.4%. It is caused by social science issues requiring students to be active in discussions and argumentations.
Parmin et al., 2022	● Concluding experimental results that are supported by valid data and facts through the presentation of experimental results	Students were asked to experiment at home by applying scientific argumentation strategies. During the experimental activities, students were equipped with skills in arguing to express their opinions orally and	Implementing an online scientific argumentation strategy effectively increases the scientific reasoning skills of prospective science teachers through investigation. Participants can make claims based on

Author, Year	The Domain of Scientific Reasoning	Learning Activities in Training Scientific Reasoning	Findings
		writing in compiling an experimental report.	evidence obtained through experiments.
Diwanata et al., 2021	● Determining empirical evidence ● Developing logical arguments ● Determining methods of inquiry to find concepts ● Making deductions, inductions, and analogies ● Distinguishing causal and correlational relations	Learning is conducted using the mobile-based application "La Bird," which facilitates students to identify bird species in Ornithology courses. Through the application, students carry out bird-watching activities that begin with determining the location of the observation, looking for data in the form of photos or videos that match the bird species being observed, then sketching the birds and identifying them.	Using the "La Bird" application improves students' scientific reasoning skills with an N-gain of 0.33 in the medium category. Because of the use of the application, students are facilitated in conducting inquiry by searching for data and evidence, which are then analyzed and evaluated to obtain conclusions about the given problems.
Atqiya et al., 2021	● Correlational reasoning ● Probabilistic reasoning ● Proportional reasoning	Students learn to identify problems and find solutions to the problems by designing investigations to collect and analyze data. In addition, students are also trained to make reason through argumentation and design prototypes based on Newton's law concepts to solve problems.	Implementing argument-driven inquiry in STEM learning can significantly improve scientific reasoning skills in the medium category. Students are facilitated to identify and investigate problems to make solutions.
Putri et al., 2020	● Reconstructing theory through experimental activities ● Evaluating evidence ● Making conclusions	Integrating inquiry learning with social science issues on global warming material. Learning activities are carried out through observation of articles related to the effects of global warming, which are then investigated to formulate solutions toward global warming through inquiry.	Integrating social science issues of global warming material in science learning can improve students' scientific reasoning skills with an N-gain of 0.43 in the medium category. Students are trained to collect and process data to find evidence

Author, Year	The Domain of Scientific Reasoning	Learning Activities in Training Scientific Reasoning	Findings
			that supports claims on an issue.
Yulianti et al., 2020	● Conservation reasoning ● Proportional reasoning	Applying guided inquiry learning on the topic of pressure. The teacher presents problems and guides students to access various sources to obtain the data needed to solve problems. Analysis and evaluation of the information are conducted to build the concept.	Implementing guided inquiry learning can improve students' scientific reasoning skills with an N-gain of 0.73 in the high category. Each step-in inquiry facilitates students to develop scientific reasoning skills.
Indahsari et al., 2020	● Conservation reasoning ● Proportional reasoning ● Identification and collection of variables ● Correlational reasoning ● Probabilistic ● Hypothesis-deductive reasoning	Using inquiry-based student worksheets assisted by Vee map scaffolding on hydrostatic pressure. Student worksheets integrate the steps of inquiry learning and are equipped with interrelated concepts and methodologies to make it easier for students to answer the given problems.	Inquiry-based student worksheets with scaffolding vee maps help improve students' scientific reasoning skills.
Malone & Schuchardt, 2020	● Control of variables ● Correlational reasoning ● Proportional reasoning ● Hypothetico-deductive reasoning	Using a spreadsheet (google sheet) modeling based on computer simulation on the topic of population growth in middle-level Biology classes. The spreadsheet presents information and data related to bacterial population growth in the form of graphs, bars, charts, and pictures. Students are asked to analyze data and make predictions of population growth under certain	The use of modeling-based simulations shows positive results in practicing scientific reasoning skills.

Author, Year	The Domain of Scientific Reasoning	Learning Activities in Training Scientific Reasoning	Findings
		conditions, then submit the results.	
Taub et al., 2020	● Formulating hypotheses ● Collecting and analyzing data to test hypotheses.	Using game-based learning with the help of "Crystal Island" in microbiology material. Activities in the game assign students to solve the mystery of a disease that affects residents on an island, including accessing information about various types and symptoms of disease, scanning food and pathogens for the source of transmission, and determining the final diagnosis of the type of disease, symptoms, and treatment.	Using "Crystal Island," which provides space for compiling hypotheses and collecting data through activities, can train scientific reasoning skills.
Susilawati et al., 2020	● Conducting observations to test hypotheses.	Learning through scientific observation and the practice of using binoculars. Students observe the sun using binoculars to formulate hypotheses to explain natural phenomena based on scientific evidence.	Observation activities and astronomical practices positively affect students' scientific reasoning skills.
Dinantika et al., 2020	● Controlling the variable ● Conversation reasoning ● Hypothesis-deductive ● Probabilistic reasoning ● Proportional reasoning ● Correlational reasoning	Using PjBL-STEM-based student worksheets on the topic of renewable energy. Students are tasked with conducting problem-solving activities, gathering information, designing project plans, carrying out projects, then communicating the result.	The use of PjBL-STEM-based student worksheets can train students' scientific reasoning skills.
Wati & Sunarti, 2019	● Correlational reasoning ● Probabilistic reasoning	Using real-life problems related to the topic of simple harmonic vibration.	Implementing case-based learning on simple harmonic vibration can improve

Author, Year	The Domain of Scientific Reasoning	Learning Activities in Training Scientific Reasoning	Findings
	● Proportional reasoning	Students are trained to identify problems and provide solutions based on the results of discussions and investigative activities. In addition, students are also trained to identify and associate facts with relevant physics concepts.	scientific reasoning skills in the medium category with an N-gain of 0.6. Students are facilitated to identify and investigate problems to make solutions.
Yanto et al., 2019	● Analyzing relationships between variables ● Describing causal relationships between phenomena ● Reviewing facts critically ● Assessing the validity of data collection procedures ● Making hypotheses ● Making conclusions	Integrating inquiry learning and contextual issues on plant nutrition, seed germination, and respiration. Learning activities include problem orientation, formulation, exploration, investigation, and conclusion.	Implementing inquiry learning is more effective than conventional learning in improving scientific reasoning skills. Students build an understanding of the hierarchy of phenomena and their relationship to various scientific concepts through investigative activities during learning.
Ortega et al., 2019	● Applying concepts in new conditions ● Rationalizing the differences between variables	Using inquiry learning through laboratory experiments on the topic of spectroscopy. Students were asked to identify problems, formulate hypotheses, find literature, plan and conduct experiments, then analyze the results and make conclusions.	Inquiry learning can train scientific reasoning skills. Students are facilitated to seek information and build concepts based on the analysis of the investigation.
Inthaud et al., 2019	● Making claims based on facts ● Presenting scientific evidence to support arguments ● Finding links between relevant aspects	Using argument-driven inquiry on the light topic. Students are faced with a problem and asked to design and conduct an investigation. Then, I presented the results as scientific arguments	There was an increase in post-test scientific reasoning skills from 11% to 48%, where 42% of students' scientific reasoning skills are in a suitable category.

Author, Year	The Domain of Scientific Reasoning	Learning Activities in Training Scientific Reasoning	Findings
		that will be reflected on with classmates.	
Radckakid & Sangpradit, 2019	● Making claims based on facts ● Presenting scientific evidence that supports arguments	Using argument-based inquiry learning on the topic of human physiology and health issues. The learning activity consists of five steps: problem recognition, investigation, data analysis, argumentation sessions, making and communicating explanations to others, and evaluation.	There was an increase in scientific reasoning skills at the 0.05 significance level. Activities in argument-based inquiry learning facilitate students to find evidence through investigation and present them during the argumentation session.
Blumer & Beck, 2019	● Identifying relationships between variables ● Evaluating the accuracy of evidence in making scientific claims	Using guided inquiry-based laboratory work modules. The module is equipped with hands-on activities, including identifying research problems, designing experimental designs to solve problems, conducting experiments, processing data, and making conclusions.	Implementing guided inquiry learning accompanied by laboratory activities can train students' scientific reasoning skills.
Janssen et al., 2019	● Problem-oriented by collecting, analyzing, and evaluating information ● Carrying out scientific research to solve problems ● Building concept constructs and applying them in different perspectives	Using scientific inquiry activities. Students are asked to define a scientific problem, develop hypotheses, conduct experiments to collect and analyze data, communicate the results, and reflect on findings and the inquiry process.	The implementation of scientific inquiry can improve scientific reasoning skills significantly.

Based on **Table 1**, various interventions are conducted during science learning to train scientific reasoning skills. The intervention can be in the form of either face-to-face or online learning. Face-to-face learning is conducted by presenting social science phenomena/cases (articles 1, 3, 7, 14-15), conducting investigation assisted by modules/worksheets (articles 2, 6, 8-9, 12-13, 16, 19-20), and implementing argument-

based learning (articles 4, 17-18). Meanwhile, online learning activities are conducted by implementing mobile apps/online simulations (articles 5, 10-11). **Figure 2** shows a radar diagram of various science learning interventions in training scientific reasoning skills.

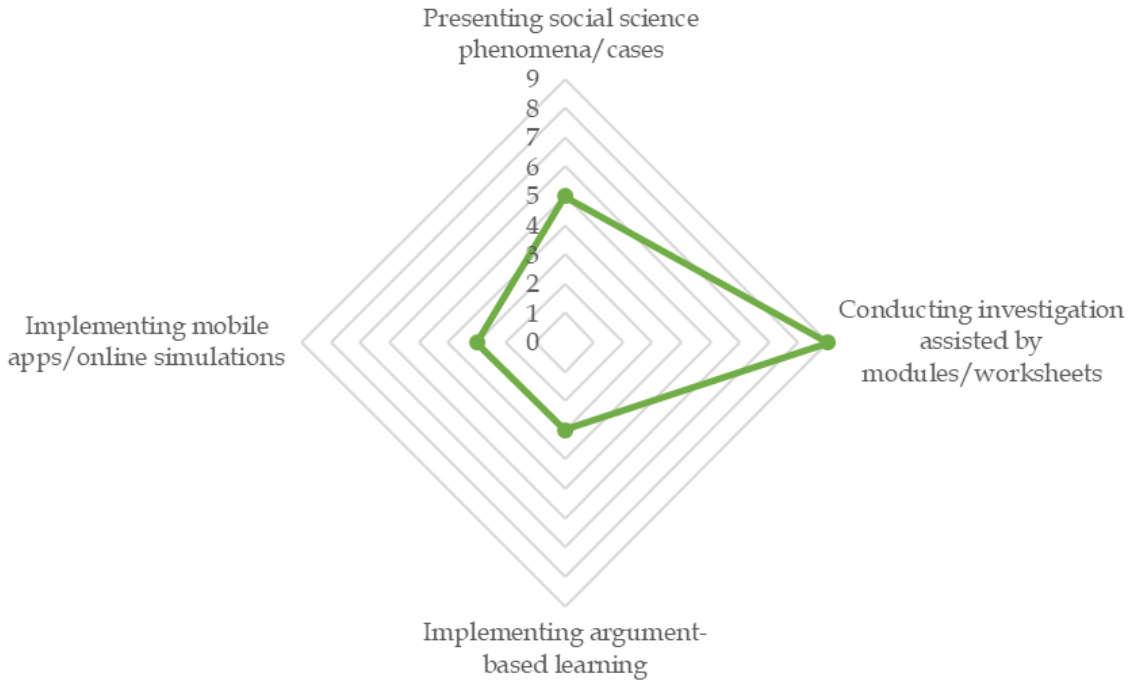

Figure 2. Trends of science learning interventions in training scientific reasoning skills.

Discussion

The Domain of Scientific Reasoning

Reasoning is one of the cognitive aspects possessed by humans. In line with cognitive development, Piaget suggested that cognitive abilities develop through four gradual stages. Each stage is marked by the emergence of new abilities and ways of processing information/knowledge (Arends, 2012). Scientific reasoning occupies a position at the highest level of cognitive abilities (formal operations). This refers to an ability to think abstractly and symbolically and solve problems through systematic experimentation. This ability involves the process of logical thinking to make conclusions about a phenomenon by connecting evidence and facts to build and evaluate claims. Kruger et al. (2020) stated that scientific reasoning is a cognitive activity that leads a person to use empirical insights to analyze and solve scientific problems.

In its development, there are two domains of scientific reasoning: scientific knowledge and scientific inquiry. Both dimensions build the definition of "Science" simultaneously. Science involves an inductive process in making hypotheses based on knowledge related to concepts and laws and a deductive process used in testing hypotheses through scientific activities to obtain knowledge. In terms of knowledge, Scientific reasoning consists of a whole pattern of reasoning, which can be characterized as hypothetico-deductive and several sub-patterns. Inhelder & Piaget (1958) refer to these subpatterns as formal operational schemes (e.g., combinatorial, proportion, correlation). In terms of process, scientific investigation is defined as procedural and conceptual activities such as asking questions, hypothesizing, designing experiments, using equipment, observing, measuring, predicting, collecting and interpreting data, evaluating evidence, performing statistical calculations, making conclusions, and formulating theories or models. Because of this complexity, researchers have traditionally limited the scope of scientific reasoning studies by concentrating on more than one dimension, domain-specific knowledge, or

domain-general strategies. This is why the dimensions of scientific reasoning ability trained in each article differed. From 20 articles analyzed, 14 articles (70%) focused on training domain-specific knowledge (articles 1, 3-4, 6, 8-10, 13, 14-19), while six articles (30%) focused on training domain-general strategies (2, 5, 7, 11-12, 20).

Learning Activities to Promote Students' Scientific Reasoning Skills

Scientific reasoning skills can be trained from secondary to higher education levels. Of the 20 articles analyzed, 11 (55%) were conducted at the higher education level, while nine (45%) were at the secondary level. This follows Piaget's theory of cognitive development, that scientific reasoning which is the highest level of thinking ability, begins to develop at 11 (Arends, 2012). Scientific reasoning skills can be trained and transferred during learning. Therefore, designing a learning environment that supports and encourages scientific reasoning skills is essential. One of the ways is through pedagogical content interventions in the form of learning activities (Engelmann et al., 2014; Janssen et al., 2019).

Science learning interventions to train scientific reasoning skills vary. However, in general, the learning activities are involved students conducting a scientific investigation, consisting of problem orientation, problem formulation, data exploration, investigation, and conclusion drawing (**Table 1**). Scientific investigations are in line with inquiry instructions. This is supported by Arends (2012) that syntax for inquiry learning is considered quite scientific in conducting investigations to find a concept and training scientific reasoning skills. The inquiry syntax consists of six phases: presenting problems, formulating hypotheses, collecting data to test hypotheses, formulating explanations based on the results of data analysis, and reflecting on problems and thinking processes. Activities in explaining phenomena and describing them as causal relationships as one of the ways to train scientific reasoning skills. These activities are carried out when students analyze data and formulate explanations. Thus, scientific reasoning skills can be trained during inquiry instruction.

Inquiry learning facilitated students to find and use various information to build conceptual understanding regarding specific topics or issues. Through investigation, students discover how knowledge can be obtained through finding, evaluating, revising, and communicating concepts (Putri et al., 2019). Orosz et al. (2023) stated that inquiry learning allows teachers to reflect on the scientific inquiry and the nature of science with the class. So that teachers can teach students to develop their own understanding and knowledge about science. This follows the constructivist views in which students have emphasized the discovery of concepts. Instruction begins with a complex problem or task to discover the essential knowledge and skills needed to solve the problem or perform the task. Thus, students can be actively involved in meaningful learning. This can be seen in the research that has been conducted (**Table 1**), where learning activities are initiated by presenting a problem, which then must be solved through investigation, e.g., Rogele et al. (2022) present the problem of how to identify birds, Yulianti et al., (2020) on the concept of pressure, and Susilawati et al., (2020) on the concept of the sun.

Besides implementing inquiry instructions, other interventions can be done by integrating inquiry syntax into teaching materials, e.g., research by Indahsari et al. (2020) integrates inquiry syntax into student worksheets, Blumer & Beck (2019) develops inquiry-based laboratory work modules, Atqiya et al. (2021) integrates investigations with the STEM approach, and Dinantika et al., (2020) integrated PjBL-STEM-based investigations in the form of student activity sheets. The findings from the previous study

indicate that integrating investigative activities in teaching materials positively impacts students' scientific reasoning skills (**Table 1**). These show that inquiry learning which requires students to conduct an investigation, can train scientific reasoning skills, whether carried out through direct instruction or integrated into teaching materials.

Another form of intervention to train scientific reasoning skills is to present social science issues within learning. Social science issues are complex social problems associated with science-related concepts, procedures, and technologies. They are widely discussed in society, e.g., genetically modified organisms (GMOs), global warming, and the use of addictive and psychotropic substances (Imanuddin & Khafidin, 2018). Social science issue-based instruction focuses on the issues and the relevant science context related to the issues (Sadler et al., 2016). Activities to find the science concept related to the issue will encourage students to make deductions, determine causal relationships, and give rational reasons from one point of view (Bryce & Day, 2014), so it will require students to make reason. Research by Khajornkhae & Nuangchalerm (2021) shows that integrating social science issues into science learning can improve scientific reasoning skills. Therefore, science learning must be designed so that students are involved and participate in discussions related to social science issues, e.g., in research by Gohner & Krell (2022) on water issues, Jansong et al. (2022) on immunization, Putri et al. (2020) on global warming, Wati & Sunarti (2019) on simple harmonic motion, and Yanto et al., (2019) on plants and nutrition, seed germination, and respiration (**Table 1**). Khairil et al. (2022) stated that using environmental issues in developing teaching materials would provide new nuances in the learning process, where students get knowledge, attitudes, and skills. The presence of social science issues in learning will encourage students to find solutions and identify relevant science concepts through investigation (Putri et al., 2020). This activity is proven to train students' scientific reasoning skills.

Interventions to train scientific reasoning skills can also be conducted by implementing argument-based learning. Argumentation facilitates students to identify concepts and provide reasons behind phenomena (Salsabila et al., 2019). Scientific reasoning involves a mechanism in explaining the process behind phenomena. Therefore, scientific reasoning skills will also be trained when students argue to identify the concepts and processes behind phenomena. This is proven by the research by Parmin et al. (2022), Inthaud et al. (2019), and Radckakid & Sangpradit (2019), which integrate argumentation within inquiry learning. During learning, students are tasked with solving problems through investigation, then asked to make rational reasons based on evidence and explain why phenomena occur according to relevant scientific concepts. The results show that after the intervention, students' scientific reasoning skills increased (**Table 1**). This is supported by Admoko et al. (2021), that the application of argument-based learning, integrated with inquiry, can improve students' reasoning abilities in explaining phenomena. Students can argue a claim with an identifiable rebuttal.

Besides face-to-face learning, scientific reasoning skills can be trained through online science learning. In this case, the use of technology and digital tools are combined with inquiry instruction to train students' scientific reasoning skills, e.g., the use of the mobile-based application "La Bird" to identify bird species in Ornithology courses through a series of investigations (Diwanata et al., 2021), computer simulation-based spreadsheet modeling on the topic of population growth (Malone & Schuchardt, 2020) and game-based learning to solve the mystery of the emergence of mysterious diseases in microbiology courses (Taub et al., 2020). This shows that integrating technology during scientific investigations can also train scientific reasoning. This is supported by Al-Ansi

et al. (2019) that the use of technology in learning has a positive and significant impact on improving the quality of learning.

The recommendation in Science Learning

Scientific reasoning skills can be trained from secondary to higher education through pedagogical content interventions in the form of learning activities. Based on the results, various activities can train students' scientific reasoning skills in face-to-face or online learning. However, the activities generally involve students actively conducting scientific investigations, starting from problem formulation, problem investigation, data exploration, data investigation, analysis, and conclusion. Therefore, science teachers can choose learning activities that meet with criteria of scientific reasoning's domain, the material taught, and the characteristics of students. In addition, teachers can make modifications by integrating inquiry activities within learning materials, learning approaches, and technology-based interactive learning media to train students' scientific reasoning skills.

CONCLUSIONS

Fundamental Finding: Scientific reasoning skills can be trained and transferred during science learning. This is done by designing interventions in the form of learning activities that require students to conduct a scientific investigation. Investigative activities can be applied in face-to-face learning through inquiry instructions or integration with social science issues, teaching materials, and the implementation of argument-based learning, as well as online learning through digital learning resources such as mobile apps, online simulations, and e-modules. **Implication:** This study aims to provide an overview of various learning activities to promote students' scientific reasoning skills in science learning. This study also recommends proper learning activities to train students' scientific reasoning skills so teachers can design effective science learning activities. **Limitation:** This study is limited to describing science learning activities that promote scientific reasoning skills in science, not in any other subject. This study provides an overview of various learning activities in science to promote students' scientific reasoning skills. **Future Research:** There is a need for further research to describe and analyze learning activities in promoting students' scientific reasoning skills, not only in science but also in any other subject. Future research must also use a learning design focusing on investigative activities to promote students' scientific reasoning skills.

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