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Case-based learning for fostering scientific literacy: A systematic review

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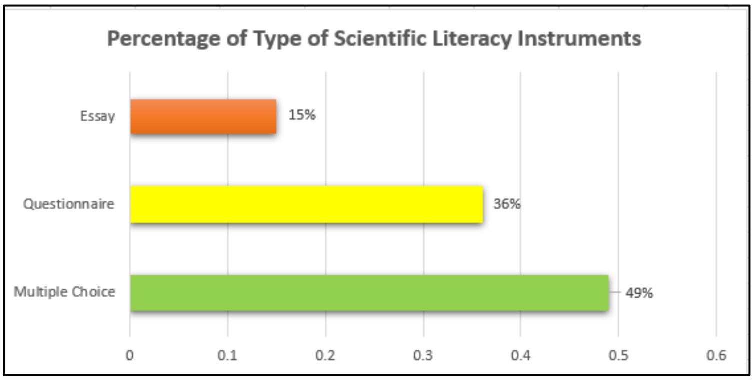
Abstract

This study aims to analyze the application of Case-Based Learning in fostering scientific literacy. This study uses the PRISMA method. A comprehensive search of peer-reviewed journals which are available through the Scopus, ERIC, and Google Scholar databases was conducted. The search terms used were: "Science Education, Scientific Literacy and Case-Based Learning". 4791 articles were found, and 45 articles were selected for review. The results showed that a) the syntax of Case-Based Learning applied in science learning consists of Inquiry-Based Learning, Problem-Based Learning, and Project-Based Learning; b) the application of Case-Based Learning in fostering effective and appropriate scientific literacy in elementary school students is Inquiry-Based Learning, in junior high and high school students is Problem-Based Learning, while in college students is Project-Based Learning; c) the instruments used to measure scientific literacy in Case-Based Learning are dominated by multiple-choice test instruments and survey questionnaires compared to essay test instruments. Thus, it can be concluded that the implementation of Case Based Learning is more dominantly prioritized in higher education in fostering scientific literacy.



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Section Editors

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Highlights

- CBL syntax applied in science learning is IBL, PBL, and PjBL
- PjBL is effectively implemented in Higher Education
- Multiple-choice tests and survey questionnaires measure scientific literacy in CBL.

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1. Introduction

Students are required to have scientific literacy in the 21st century (Novitasari, 2018). Scientific literacy is very important because it may develop the following abilities: a) knowing and understanding scientific ideas and methods, b) finding answers to questions that arise from curiosity about everyday life, c) explaining and predicting what will happen, d) taking part in social interactions that require familiarity with scientific literature, e) solving problems in science and technology, f) assessing scientific information based on its origin and how it is processed, g) using data to draw conclusions and arguments, and the ability to assess arguments (Dewi *et al*., 2022; Pertiwi *et al*., 2018). Scientific literacy is one of the demands of 21st century as science is a field of study that can explain things that happen in everyday life (Rahayu, 2017). Therefore, scientific literacy has become a demand of the times. Educating students to have scientific literacy is the main goal in every science education reform as a transferable outcome (Laksono, 2018). The results of PISA 2018 show that Indonesia is still ranked at the lowest level of science literacy scores with an average score of 396 from the world science literacy standard of 493 (OECD, 2018).

Case-based learning (CBL) can help improve students' scientific literacy because it forces them to make connections between their learning and real-world contexts. CBL emphasizes that knowledge concepts are better understood and remembered when students are given issues that are relevant to everyday life (Das, 2018). CBL can help students develop critical thinking, problem-solving, and group skills so that they can find problems, make hypotheses, search for data, conduct experiments, find answers, and find the best solutions to problems (Dewi *et al*., 2022; Jamari *et al*., 2018). CBL provides students with the opportunity to analyze the material first, introduces core knowledge domains, and encourages students to seek other knowledge domains that are relevant to the problem (Çam and Geban, 2017; Günter and Alpat, 2019). CBL involves problems related to environmental cases, conditions, situations, or students' visions of the future (Lei *et al*., 2016). Cases can be in the form of stories or readings related to the material being studied so that students can think about how to solve the problem (Cáceres-Jensen, 2021). The use of realistic narratives in CBL can provide opportunities for students to synthesize information from different sources (Williams, 2020).

Case-Based Learning presents authentic problem scenarios that can be explored through two approaches: retrospection, which involves evaluating the effectiveness of existing solutions, and action, which focuses on actively addressing the case (Ballard and Mooring, 2021). This method has been found to enhance students' motivation and foster positive scientific attitudes in chemistry learning (Çam and Geban, 2017). In the context of analytical chemistry, CBL also contributes to improved academic performance and greater learner satisfaction (Günter *et al*., 2019). Students can easily use biochemistry laboratory equipment in online experiments through the use of CBL (Thibaut and Schroeder, 2020). Students in environmental chemistry classes can learn the idea of "green chemistry" through case-based learning tools (Ballard and Mooring, 2021). CBL can improve student learning outcomes in environmental chemistry classes (Günter and Alpat, 2019).

Although CBL has been widely researched, its implementation still presents several challenges. For instance, lecturers often struggle to design relevant cases that can be effectively used as instructional materials (Çam and Geban, 2017). Additionally, developing a coherent sequence of content that aligns with learning objectives while managing workload and time constraints remains problematic (Bi *et al*., 2019; Jamari *et al*., 2018). On the students' side, difficulties arise in comprehending the cases presented, which hampers their ability to construct appropriate responses (Günter *et al*., 2019). Learners also tend to face obstacles in articulating and summarizing conclusions clearly and concisely (Suwono *et al*., 2017). Furthermore, the lack of suitable limiting resources that support independent case-solving limits their ability to receive adequate guidance (Ballard and Mooring, 2021; Thibaut and Schroeder, 2020).

Therefore, it is necessary to conduct a literature review on the application of case-based learning in fostering scientific literacy. The importance of the present study consists of CBL is related to scientific cases that can be used as a starting point for asking questions, applying, and deepening scientific knowledge (Yano *et al*., 2022). Scientific problems are closely related to everyday life, thus requiring students to have scientific literacy (Bag and Calik, 2017; Cigdemoglu *et al.,* 2017). Scientific literacy is related to competence in understanding the framework of thinking and utilizing scientific knowledge (Broman and Parchmann, 2014; Thummathong and Thathong, 2018; Ültay and Çalık, 2012; Wiyarsi, 2020).

From the description above, the impact on teachers and researchers who implement CBL can provide an overview of CBL learning. The significance of this study lies in its potential to influence teachers' pedagogical perspectives by demonstrating how CBL can be effectively utilized to enhance students' scientific literacy and deepen their understanding of science concepts. To achieve these objectives, a systematic study of the CBL approach needs to be implemented as one of the promising learning strategies in fostering students' scientific literacy. This study aims to analyze the implementation of CBL that is effectively applied in fostering scientific literacy. The research questions from this literature study are: a) How is the syntax of CBL in science learning? b) How effective is CBL in fostering scientific literacy? c) What instruments are used to measure scientific literacy in CBL?

2. Method

This study aims to analyze the characteristics of CBL interventions in the research literature to determine how CBL is used to foster scientific literacy. The research method used is PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses), a tool and guide for evaluating systematic reviews and meta-analyses (Liberati *et al*., 2009). A comprehensive search of peer-reviewed journals which are available through the Scopus, ERIC, and Google Scholar databases was conducted. The search terms used were the following: "Science Education, Scientific Literacy and Case-Based Learning". Given the purpose of the review, only articles that connect CBL with scientific literacy or the nature of science were used. Thus, this article examines CBL interventions solely based on their usefulness for fostering scientific literacy. The following is a mapping of the articles in **Fig. 1**.

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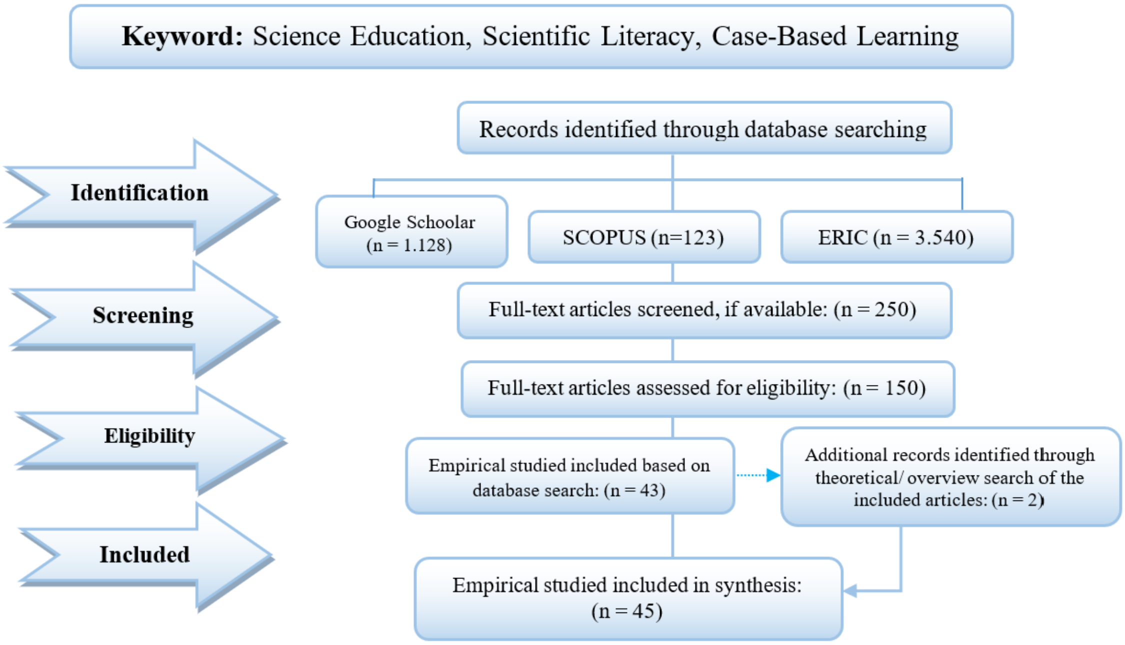

Figure 1. The Flowchart illustrates the mapping of the selection of relevant articles for systematic review.
Source: Adapted from Dewi and Rahayu (2023).

2.1. Identification step

A literature study was conducted by taking scientific article data from reputable international journals with Scopus Q1-Q4 index. The database sources used were Google Scholar, Scopus, and Eric with search keywords including 1) Science Education, 2) Scientific Literacy, and 3) Case-Based Learning. Article searches were limited to the last 10 years from 2013-2023. The results of the article search on these database sources obtained a total of 4,791 articles, including Scopus articles (n = 123), Google Scholar (n = 1,128), and Eric (n = 3,540). The articles were then selected based on: (a) reputable international journal articles; (b) articles are English versions; (c) papers reporting research on CBL treatments or intervention components (articles from practitioner journals that have not undergone peer review are not included), (d) papers explaining what the intervention is and how it works, and (e) articles discussing the actions taken for students and learners.

2.2. Screening step

The library data filtering process uses the "Article" category and retrieves 150 articles from Google Scholar, 80 from Scopus, and 20 from Eric. After that, the article title was filtered explicitly for the words "Science Education", "Scientific Literacy", or "Case-Based Learning", resulting in 100 articles found on Google Scholar and 50 articles on Scopus. Then, filtering was carried out again, focusing on "Education Articles", and 75 articles were obtained from Google Scholar, while 25 articles were obtained from Scopus. Furthermore, filtering was carried out by focusing on the article quartile "Article Q1-Q4", resulting in 70 articles obtained from Scopus and 20 articles from Google Scholar.

2.3. Eligibility step

Eligibility requires studies to concentrate on Science Education or Scientific Literacy or CBL. Our definition of Science Education or Scientific Literacy or CBL includes four essential characteristics that serve as selection parameters: a) the subject matter of the study must have real significance for future societal progress; b) the problem must be interdisciplinary and unstructured, incorporating a complexity of different elements, interests, and potential perspectives; c) scientific knowledge is essential for reasoning about the topic and making insightful conclusions; d) ethical perspectives and values are intrinsic components of the decision-making process, regardless of their explicit consideration during the student's educational experience. Only research publications written in English were considered eligible for inclusion in the systematic review. Studies had to be published in peer-reviewed scientific journals classified as level 1, level 2, level 3 or level 4 on the Scopus scale. When selecting the most appropriate journal, the research objectives and publication year of the article were considered. This review used research not listed on beallslist.net, namely leading journals and publication years ranging from 2013 to 2023. The eligibility criteria for the review included the evaluation of Case-Based Learning research in fostering scientific literacy and empirical studies. In the review, the exclusion criteria included articles that were not related to the topic, duplications, and rejected papers or abstracts only. Articles without accessible full text were excluded. The analysis excluded articles that did not focus on science education and research whose scope was unrelated to the current evaluation. We combined studies completed in all countries. The results of the eligibility assessment obtained 65 articles completed by two independent researchers coded the articles. Initial agreement between reviewers was 80%, and consensus was reached through discussion (final agreement: 100%).

2.4. Included step

The final stage involved reviewing "full papers" and "removing duplicates" to yield 45 articles. Articles that met the exclusion criteria were the 45 articles acceptable for review. Consequently, 45 publications were selected for analysis according to the research topic. The next section presents insights from the evaluated papers, accompanied by selected findings for direct synthesis and analysis. Two researchers independently coded the articles, achieving a rater agreement of 95% due to the objective nature of the factors assessed from the text.

3. Results and discussion

3.1. CBL syntax in science learning

The CBL is applied in science learning through three main active learning models, namely Inquiry-Based Learning (IBL), Problem-Based Learning (PBL), and Project-Based Learning (PjBL). The following graph shows the percentage of CBL implementation in the three learning models.

Figure 2 shows that CBL is used in three different ways, namely IBL (used in 24 of 45 studies, representing more than half of the total), PjBL (used in 11 of 45 studies, representing a quarter of the total), and PBL (used in 10 of 45 studies, representing three-quarters of the total).

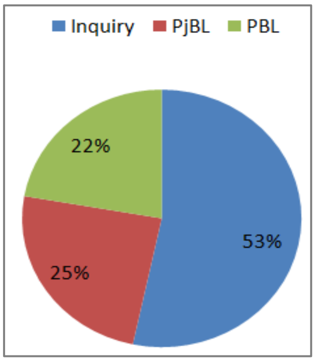

Figure 2. Percentage of CBL variant application.
Source: Elaborated by the authors.

These three variants of CBL strategies, and the dominant application in science learning is IBL. Case-based learning is a teaching method that places students at the heart of the classroom and encourages them to actively participate by working in teams to solve real-world problems (Jamari *et al.*, 2018). In the context of science education, the three components of CBL type differentiation, namely IBL, PBL, and PjBL—are all part of the same learning system called Active Learning (Brundiers and Wiek, 2013; García-Ponce *et al.*, 2021; Hong and Yu, 2017; Lei *et al.*, 2016). Therefore, CBL is used in three different pedagogical models IBL, PBL, and PjBL models (Dewi *et al.*, 2022).

3.1.1. CBL in inquiry-based learning

The IBL is a learning approach that fosters students' self-confidence to become individuals who think systematically, logically, and critically throughout the learning process. Educators not only transfer knowledge to students but also provide opportunities for students to discuss and collaborate actively, both independently and in groups, through experimental activities. Inquiry-Based Learning consists of six stages: problem orientation, problem formulation, hypothesis creation, exploration, hypothesis testing, and finally conclusion formation (Li *et al.*, 2022; Morsink *et al.*, 2021). Table 1 presents the syntax of CBL in IBL.

3.1.2. CBL in problem-based learning

The PBL offers students the opportunity to acquire information and develop problem-solving skills (Dastgeer and Afzal, 2015; Leon *et al.*, 2015). The stages of the scientific method in PBL are: (1) identifying problems, (2) collecting data, (3) analyzing data, (4) solving problems based on existing data and its analysis, (5) choosing how to solve problems, (6) planning the distribution of problem-solving, (7) testing the established plan, and (8) taking action to solve problems (Lutsenko, 2018; Veale *et al.*, 2018). The syntax of CBL in problem-based learning is presented in Table 2.

The advantages of PBL are: a) developing students' skills in various aspects of life; b) enhancing their creative and analytical thinking abilities; c) encouraging scientific reasoning and independent work; and d) fostering critical reflection on newly acquired knowledge and personal abilities (Etiubon and Ugwu, 2016; Major *et al.*, 2021; Marincean, 2021). Meanwhile, the disadvantages of PBL are: a) students do not have the belief that the problems being studied are challenging to solve so they are not interested in trying; b) the learning process requires textbooks to support students' understanding during learning activities; c) it takes a long time to complete the learning cycle; d) not all learning materials can be applied using this model (Alt and Raichel, 2022; Mann *et al.*, 2021; Tal *et al.*, 2021).

Table 1. The syntax of CBL in inquiry-based learning.

CBL Type	CBL-IBL syntax
IBL	**1) Orientation** At this stage teachers are required to create a conducive and pleasant atmosphere for learning. **2) Formulating Problems** Problem creation is the process of figuring out what problems need to be solved. **3) Formulating hypotheses** The teacher asks the students to come up with short-term solutions or guesses (hypotheses) to the problems they have been talking about. **4) Collecting Data** Students are asked to find evidence to support their theories as a way to validate hypotheses through experiments, presentations or class discussions. **5) Testing Hypotheses** From the data collected, it is then used to test the hypothesis so that it will be proven whether the hypothesis is true or false. **6) Drawing Conclusions** After all the steps to gather evidence have been taken, conclusions can be made. The results of the research can then be shared with other students through talks.

Source: Adapted from Chu *et al.* (2021) and Morsink *et al.* (2021).

Table 2. CBL syntax in problem-based learning.

CBL Type	CBL-PBL Syntax
PBL	**1) Student orientation to problems** The teacher introduces the problem to be solved by the students. **2) Organizing students to study and discuss** The teacher helps students organize themselves to solve the problem. **3) Guiding individual and group investigations** The teacher guides students in conducting investigations and collecting data. **4) Analyze and evaluate the solving process** The teacher and students analyze and evaluate the problem-solving process. **5) Develop and present the work** Students communicate their findings and proposed solutions.

Source: Adapted from García-Ponce *et al.* (2021) and Veale *et al.* (2018).

3.1.3. CBL in project-based learning

In the PjBL, CBL is a way of learning that starts with problems as the first step in gathering and integrating new information based on real-life experiences (Bressiani, 2020). This is done to help, encourage and guide learners to focus on cooperation by involving group work and helping learners to focus on their development (Paristiowati, 2017). The characteristics of this learning are a) learner-focused learning; b) project-based in its learning; c) developing active participation of learners; d) fostering initiative and independence from learners; e) exercising collaboration and responsibility for accessing and managing information to find solutions; f) train students' critical thinking and creativity; g) evaluation is carried out periodically because participants reflect; h) a learning project produces an exact product or output; i) facilitators accompany during the learning process (Chowdhury, 2015; Jian and Yang, 2015; Lu, 2021). The syntax of CBL in PBL is presented in **Table 3**.

Table 3. CBL syntax in project-based learning.

CBL Type	CBL-PjBL Syntax
PjBL	**1) Prepare project inquiries or assignments** Questions should get students to do a project or exercise.
	2) Design or plan for the project Planning includes information about the supporting tasks that need to be done, as well as the tools and materials that will help finish the job.
	3) Prepare a schedule for project completion Activities at this stage include: (a) making a schedule, (b) figuring out when the job needs to be finished (the deadline), and (c) coming up with new ways to solve problems, (d) giving an account of why you chose a different method.
	4) Monitor project activities and progress The lecturer keeps an eye on what the students are doing while the job is being done.
	5) Test results Display projects can be used to test the results.
	6) Evaluate activities or experiences Reflection on the projects that have been done and what they have led to (Ruslan et al., 2021; Turek, 2016).

Source: Elaborated by the authors.

The advantages of PBL are: a) making students want to learn more, helping them do valuable work, and rewarding work; b) improving students' problem-solving skills; c) making students more active and able to solve difficult problems; d) increasing collaboration between students; e) helping students to learn and use communication skills; f) providing students with experience in learning and practicing organizing projects and allocating time and other resources such as tools to complete tasks; g) offering learning opportunities that engage students in complex ways and are made to change like the real world; h) enabling students to gather information, demonstrate their knowledge, and apply it in real-world contexts; i) creating a light class where both teachers and students can enjoy their work (Chowdhury, 2015; Jian and Yang, 2015; Lu, 2021; Ruslan *et al.*, 2021; Turek, 2016). Meanwhile, the disadvantages of project-based learning are: a) it takes a lot of time in the learning process; b) teachers must continue to monitor every student activity; c) students have difficulty solving very complex problems (Miller *et al.*, 2021).

Thus, CBL learning in IBL, PBL, and PjBL have similarities in directing students to think about solving problems. Meanwhile, the difference is that in IBL and PBL there are stages of problem orientation, while in PjBL there are stages of compiling questions or project assignments. Furthermore, the second stage in IBL is formulating problems, and in the PBL stage, formulating problems is included in the problem orientation stage. In contrast, in PjBL, formulating problems is integrated into the compilation of questions or project assignments. The 3rd stage of IBL is formulating hypotheses; in PBL, formulating hypotheses is organizing students to learn and discuss, while in PjBL, formulating hypotheses is at the stage of designing or planning a project. The 4th stage in IBL is collecting data. In PBL, data collection occurs at the stage of guiding individual and group investigations. In PjBL, data collection is at the stage of compiling a project completion schedule and monitoring project activities and progress. The 5th stage in IBL is testing hypotheses. In PBL, hypothesis testing is at the stage of analyzing and evaluating the problem-solving process, while in PjBL, hypothesis testing is at the stage of testing the results. The 6th stage in IBL is concluding. In PBL, concluding is at the stage of developing and presenting work, while PjBL concludes at the stage of evaluating activities or experiences. In addition, the problems given in IBL aim to train students to think scientifically, while problems in PBL aim to train students to connect knowledge with environmental problems. Problems in PjBL aim to train students to have skills in solving real problems that occur in society.

The CBL is applied in three learning models, namely IBL, PBL, and PjBL. This is because CBL is based on the design of learning models from variants of cognitive learning models and is integrated into the same learning system, namely Active Learning (Brundiers and Wiek, 2013; García-Ponce *et al.,* 2021; Hong and Yu, 2017; Lei *et al.,* 2016). CBL uses a theoretical framework based on constructivist learning theory and cognitive learning theory. Constructivist learning theory is a theory based on observations and scientific studies of how students learn (McCourt, 2022). In constructivism, prior knowledge plays an important role in actively building knowledge by asking questions, exploring, and assessing what is known (Fatimah *et al.*, 2022). Constructivist theory emphasizes two key characteristics in the educational process. First, good problems are needed to stimulate exploration and reflection in constructing knowledge. Second, requires interaction with others to solve problems together (Banihashem *et al.*, 2022). Learning that emphasizes the scientific problem-solving process requires students to be actively involved in the learning process (Kayii and Akpomi, 2022). Cognitive theory is based on two assumptions. First, knowledge acquisition is an interactive process of students with their environment that actively changes students and their environment. Second, students construct their knowledge by connecting new information and previously obtained information into a meaningful knowledge structure (Picauly, 2016). In line with this, Picauly (2016) and Sutarto (2017) identify three core cognitive processes: acquiring new information, transforming that information, and evaluating its relevance and accuracy. Through these processes, students are expected to construct knowledge meaningfully and relate it to new contexts to enhance their scientific literacy.

3.2. The Effectiveness of CBL in fostering scientific literacy

CBL has been proven effective in fostering scientific literacy at various levels of education, especially in higher education. The percentage of CBL use at educational levels is shown in **Fig. 3**.

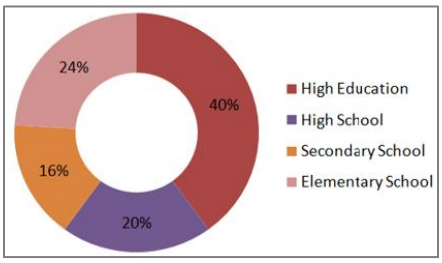

Figure 3. Percentage of CBL Implementation at Education Level.
Source: Elaborated by the authors.

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Figure 3 shows that the trend of CBL implementation is highest at the tertiary level, accounting for 40% of the total. This predominance is likely due to the main objective of CBL being to foster empathy and critical reasoning among students. In Bloom's taxonomy adapted for CBL, the targeted cognitive levels include analysis and evaluation (Dewi *et al.*, 2022).

Moreover, critical thinking itself is characterized by a deep, analytical approach that goes beyond superficial understanding—seeking root causes, interpreting underlying meanings, and exploring hidden dimensions of events (Erna *et al.*, 2021; Hong and Yu, 2017). Consequently, the traditional lecture-based classroom format is shifting toward more interactive methods, such as confirmation, discussion, and even debate (Herranen, 2019). Through this approach, CBL engages students to be more active and creative in analyzing real-life situations (Das, 2018).

In practice, CBL scenarios or case studies are utilized to strengthen students' reasoning abilities, deepen content knowledge, and improve problem-solving skills (Çam and Gebran, 2017). In the context of higher education, this model has been shown to enhance students' interest and attitudes toward chemistry learning (Çam and Geban, 2017). Additionally, its implementation in analytical chemistry laboratory activities has been associated with increased student achievement and satisfaction (Günter *et al.*, 2019), as well as better support for online experimental learning (Thibaut and Schroeder, 2020). Furthermore, CBL-based environmental chemistry modules have been found effective in introducing students to green chemistry concepts (Ballard and Mooring, 2021) and improving both learning outcomes and scientific attitudes (Günter and Alpat, 2019).

3.2.1. Application of CBL in fostering scientific literacy in elementary school

At the elementary school level, CBL is most effectively implemented through IBL. The percentage of IBL use at the elementary school level can be seen in **Fig. 4**.

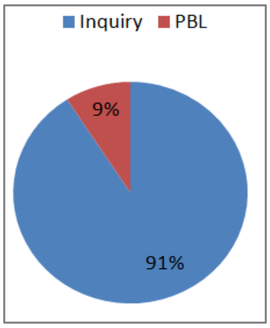

Figure 4. Percentage of CBL implementation at the elementary level.
Source: Elaborated by the authors.

Figure 4 shows that the trend of IBL implementation with the highest percentage of 91% is at the elementary school level. This is because CBL in IBL is a practical learning model that can foster elementary school students' scientific literacy. Inquiry-Based Learning emphasizes student involvement in gaining learning experiences in organizing, researching, and solving problems in everyday life (Dastgeer and Afzal, 2015). The level of cognitive development of elementary school students is at the concrete operational stage where students can think through natural objects and real problems (Piaget, 2003). Elementary school students exhibit characteristics such as playfulness, physical activity, collaborative work, and hands-on learning (Tadjer *et al.*, 2022). Therefore, teachers should implement learning according to the characteristics of elementary school students and emphasize student activities, evaluating, and analyzing what they learn. The application of IBL can build students' critical thinking skills through meaningful learning experiences (Vilardo, 2017). In addition, IBL can provide opportunities for elementary school students to gain real-world experience during the learning process, allowing them to independently discover, construct, and develop their insights and skills in various aspects of development (Herranen, 2019).

3.2.2. Application of CBL in fostering scientific literacy of high and secondary school

At the junior and senior high school levels, the most effective CBL is implemented through PBL. The percentage of PBL use at the junior high and senior high school levels is illustrated in **Fig. 5**.

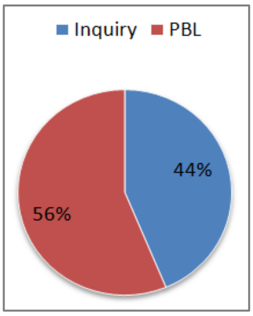

Figure 5. Percentage of CBL implementation at High and Secondary school level.
Source: Elaborated by the authors.

Figure 5 shows that the trend of implementing PBL with the highest percentage of 56% is at the junior high and senior high school levels compared to IBL at 44%. This is because junior high and senior high school students are more ready to learn independently and develop critical thinking, collaboration, and communication skills so that PBL can be more effective in helping students understand more complex concepts. The results of the study show that PBL is an effective teaching method that can make students interested in learning (Dastgeer and Afzal, 2015). Additionally, the PBL model can foster critical and creative thinking skills while developing open collaboration skills in students (Nurjaman and Sari, 2017). Furthermore, PBL encourages students to learn new concepts, helps them use what they already know to solve real-world problems, and improves their ability to think critically (Alt and Raichel, 2022; Mann *et al.,* 2021; Tal *et al.,* 2021). Thus, it can be concluded that the application of CBL in fostering effective and appropriate scientific literacy in junior high and high school students is CBL in PjBL.

3.2.3. The Application of CBL in fostering scientific literacy of high education

At the higher education level, the most effective CBL is implemented through PjBL. The percentage of PjBL use at a higher education level is shown in **Fig. 6**.

Figure 6 shows that the trend of implementing PjBL, with the highest percentage of 61%, is at the higher education level compared to IBL at 39%. This is because PjBL is project-oriented, which emphasizes more on preparing students to solve real-world challenges (Bressiani, 2020). In PjBL, the most crucial aspect of the learning process is focusing on the issues underlying a given task (Evans *et al.,* 2022). In addition, PjBL focuses on the targets of problem-solving, critical thinking, and contextual thinking training with real-world challenges, as well as facilitating decision-making skills by helping students identify sources, references, and principles (materials) through problem-solving strategies in the following ways: (a) actively participating and focusing on discussions; (b) stimulating students' thinking power by asking questions; (c) encouraging students to analyze problems, synthesize problems, conduct evaluations, and compile summaries of evaluation results (Mahanan *et al.*, 2021; Rahmawati *et al*., 2021; Santyasa *et al*., 2021). Thus, it can be concluded that the application of CBL in fostering effective and appropriate scientific literacy in students is PjBL.

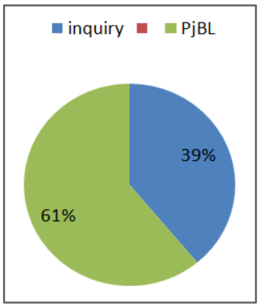

Figure 6. Percentage of CBL implementation at the College level.
Source: Elaborated by the authors.

3.3. Instruments used to measure scientific literacy in CBL

Scientific literacy can be transformed into a scientific literacy assessment; PISA 2018 identifies three significant dimensions of scientific literacy: the science process, science content, and the context of science applications (OECD, 2018). Identifying and analyzing evidence, as well as explaining findings, are all examples of the mental processes that fall under the umbrella of "process science" (Dewi *et al*., 2019). When we refer to "science content", we mean the ideas that will help us make sense of the world around us and the ways in which humans have altered it (Vogelzang, 2020). Health and nutrition, in the individual context, and the global climate system in the broader context are examples of circumstances where scientific processes and concepts can be applied and understood (Rahayu, 2017). Various instruments often used in measuring students' science literacy are multiple-choice test instruments, survey questionnaire instruments and essay test instruments. **Figure 7** presents the percentage of the types of instruments used in measuring scientific literacy.

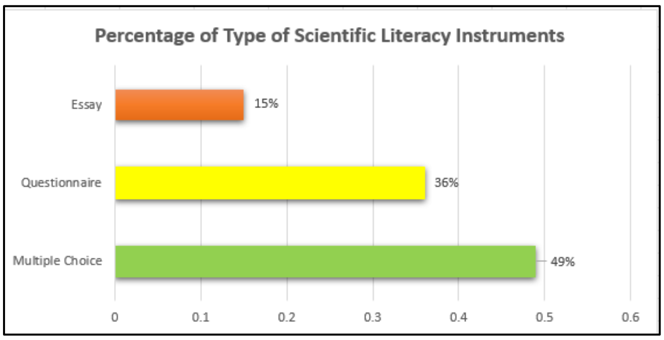

Figure 7. Percentage of types of scientific literacy instruments.
Source: Elaborated by the authors.

Figure 7 shows that most studies used multiple-choice instruments, followed by questionnaires and essays. Multiple-choice instruments have characteristics in measuring scientific literacy, especially knowledge and competence. The knowledge aspects in scientific literacy are content knowledge, procedural knowledge, and understanding of the reasons underlying procedures and the justification for their use (epistemic knowledge) (Dewi *et al.,* 2022).

3.3.1. Knowledge aspects of scientific literacy

3.3.1.1. Content knowledge

The term "scientific knowledge" is used interchangeably with "knowledge of the natural world" (OECD, 2018). The following are the criteria used to evaluate students' knowledge in the central scientific disciplines of physics, chemistry, biology, earth science, and space science: a) practicality: the extent to which one may use scientific information in their daily lives varies; b) This information represents fundamental scientific ideas or hypotheses; c) knowledge chosen for individuals' stages of growth (Pujawan *et al*., 2022).

3.3.1.2. Procedural knowledge

Procedural knowledge consists of: a) the concept of a variable; b) understanding scales, categories, and continuous variables and other forms of quantitative and qualitative measurement; c) ways to evaluate and reduce ambiguity; d) instruments to ensure data precision, that is, the degree to which measurements are similar to each other; e) techniques for abstracting and representing data, usually using tables, graphs, and diagrams; f) avoiding ambiguous results and identifying potential causes and causal pathways through the use of tactics to control variables in experimental designs or randomized controlled trials; g) the nature of designs appropriate to scientific questions (Holbrook and Rannikmae, 2009).

3.3.1.3. Epistemic knowledge

Knowledge of constructions, or epistemic knowledge, is crucial for developing scientific understanding. Their role is to justify the knowledge generated by science, e.g. hypotheses, theories and observations (Holbrook and Rannikmae, 2009). It plays an important part in the way we know what we know (Roberts and Bybee, 2014). The scientific method relies on epistemic knowledge as a foundation for the validity of its claims about the natural world and as a justification for the procedures and practices by which scientists arrive at those claims.

3.3.2. Aspects of scientific literacy competency

PISA assessment in science literacy gives priority to several competencies, namely: 1) understanding the nature of scientific inquiry, being able to recognise problems amenable to scientific investigation, and recognise key terms associated with scientific knowledge; 2) explaining scientific occurrences by identifying relevant descriptions, explanations, and forecasts, and applying scientific knowledge to a specific context; 3) communicate findings, including evidence and reasoning, and reflect on the social implications of scientific findings; use scientific evidence, i.e. interpret scientific evidence and draw conclusions; provide reasons for supporting or rejecting conclusions; identify assumptions made in reaching conclusions (OECD, 2018). Scientific literacy assessment is shown in **Fig. 8**.

Figure 8. Charts for constructing and analyzing scientific literacy test instruments.
Source: Adapted from OECD (2018).

Meanwhile, questionnaires are the instrument of choice for assessing students' scientific literacy, particularly when examining their perspectives on science. The goal is to gauge students' perspectives on science in three key areas: scientific curiosity, critical evaluation of research methods, and ecological consciousness (OECD, 2018). Curiosity about and interest in science and scientific problems, a desire to learn more about and practice science through a variety of means, and a willingness to pursue a career in the field are all examples of scientific interest. An analysis of the scientific method, or the use of facts rather than faith to explain the world around us and the need for critique in determining whether an idea is sound. Concern for the environment and a desire to live sustainably are at the heart of environmental awareness, together with a willingness to engage in and advocate for environmentally positive actions (Roberts and Bybee, 2014).

4. Conclusions

Based on the literature review, several key findings were identified regarding the implementation of Case-Based Learning (CBL) in science education: a) there is a differentiation in the application of CBL methods—namely Inquiry-Based Learning (IBL), Problem-Based Learning (PBL), and Project-Based Learning (PjBL)—which are integrated within the broader framework of Active Learning; b) the use of each method varies across educational levels: IBL is predominantly used in elementary education, PBL is more common at the junior and senior high school levels, while PjBL is primarily implemented in higher education; c) the measurement of science literacy is mostly conducted using multiple-choice tests and survey questionnaires, with essay-based assessments used less frequently. The findings of this study provide insights into the implementation of CBL strategies and the selection of appropriate science literacy assessment tools across different educational stages. To enhance the effectiveness of CBL in science learning, it is recommended that the stages of CBL—such as case formulation, investigation, analysis, and reflection—be optimized and carefully aligned with curriculum objectives and students' developmental needs. This alignment will help ensure that the CBL approach is not only pedagogically sound but also adaptable and efficient across diverse learning environments.

Authors' contribution

Conceptualization: Citra Ayu Dewi; **Data curation:** Citra Ayu Dewi; Sri Rahayu; **Formal Analysis:** Muntholib Muntholib; Parlan Parlan; Habiddin Habiddin; **Funding acquisition:** Not applicable; **Investigation:** Citra Ayu Dewi; **Methodology:** Citra Ayu Dewi; Habiddin Habiddin; **Project administration:** Citra Ayu Dewi; **Resources:** Citra Ayu Dewi; **Software:** Not applicable; **Supervision:** Sri Rahayu; **Validation:** Muntholib Muntholib; Parlan Parlan; Habiddin Habiddin; **Visualization:** Sri Rahayu; **Writing – original draft:** Citra Ayu Dewi; **Writing – review & editing:** Sri Rahayu; Muntholib Muntholib; Parlan Parlan; Habiddin Habiddin.

Conflict of interest

The authors declare that there is no conflict of interest.

Data availability statement

Data sharing is not applicable to this article, as no new datasets were generated or analyzed during the current study.

Artificial Intelligence usage statement

OpenAI's ChatGPT was used during the manuscript revision process to assist with English language editing, grammar correction, sentence clarity, and improvement of academic readability. The AI tool was not used to generate research data, conduct data analysis, determine study findings, or make scientific interpretations. All AI-assisted revisions were critically reviewed, verified, and approved by the authors, who take full responsibility for the accuracy, integrity, and content of the manuscript.

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