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Learning Models in Mathematics and Science Education to Improve High Order Thinking Skill (HOTS): A Systematic Literature Review

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High Order Thinking Skills
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SLR

Abstract

This systematic literature review examines mathematics and science education learning models that improve Higher-Order Thinking Skills (HOTS). The review focuses on studies from 2000 to 2023, addressing Indonesia's need to enhance HOTS in response to low performance in global assessments like PISA. Using the PRISMA method, 20 studies were analyzed based on criteria such as HOTS focus and relevance to primary and secondary education. Findings reveal that Inquiry-Based Learning (IBL) is the most commonly used model across disciplines, promoting critical thinking and problem-solving. Problem-Based Learning (PBL) is also widely applied, particularly in senior high schools, encouraging creativity through real-world problems. Discovery Learning, though less frequent, fosters independent inquiry in chemistry education. The study concludes that inquiry-driven and problem-solving models are key to developing HOTS, especially in secondary education, where cognitive demands increase. These models should be integrated into curricula to meet the challenges of the Fourth Industrial Revolution.

1. INTRODUCTION

The Industrial Revolution 4.0 in the world of education requires students to have high-order thinking skills because the ability to think creatively, think critically, and solve problems is necessary to face life's challenges in the future. In order to improve these abilities, students must be able to think at a high level. The Indonesian government is currently trying to produce graduates who have high-order thinking skills. The government's efforts are due to the results of the PISA (Programme International Student Assessment) evaluation initiated by the Organisation for Economic Co-operation and Development (OECD). The PISA test is a study conducted to evaluate the education system, and the test was followed by more than 70 countries around the world. The results of the PISA test show that students in Indonesia are not yet accustomed to high-order thinking skills. This is because learning in Indonesia is more directed at memorizing and applying rather than analyzing and solving problems. Indonesia is ranked below average based on the results of the PISA test. The PISA test obtained by Indonesia in 2018 placed Indonesia in 74th place for literacy tests, 73rd for mathematics, and 71st for science (OECD, 2019). Although the 2022 PISA test results show an increase in Indonesia's ranking from 81 participating countries, Indonesia is still included in the category of countries with below-average test scores compared to other countries (OECD, 2023). The low PISA test results obtained by Indonesia are due to students' low high-order thinking skills.

HOTS is an ability that requires critical and creative thinking to solve a problem. Someone who can think at a high level must be able to analyze, connect, and interpret the root of the problem to obtain new ideas and solutions. HOTS is part of the cognitive domain in the revised version of Bloom's Taxonomy. HOTS is in the cognitive dimension of analyzing (C4), evaluating (C5), and creating (C6) (Anderson & Krathwohl, 2001). High order thinking skills are complex thinking skills and require high intellectual involvement. These abilities include the ability to analyze, evaluate, and create. High order thinking skills are critical for students to solve problems, make decisions, and think critically (Habiddin & Page, 2020). In today's era of globalization, high order thinking skills are becoming increasingly important. This is because the rapid development of science and technology requires students to be able to think critically and creatively. Students must be able to analyze information, evaluate various alternatives, and create innovative solutions. Learning is one factor that can improve students' high-order thinking skills. The right learning model can encourage students to think actively and critically (Brookhart, 2010).

The low level of higher-order thinking skills among students in Indonesia has become a concern in educational research. Several studies have highlighted this issue and provided insights into the factors contributing to this phenomenon (Habiddin, Ashar et al., 2022; Puspita et al., 2020). A study on high-order thinking skills of junior high school students in Jember Regency, Indonesia, was conducted using PISA standard questions. The findings showed that many students showed low analytical, evaluative, creative, logical, and reasoning skills. This study provides empirical evidence of Indonesian students' low level of higher-order thinking skills (Kurniati et al., 2016). Furthermore, it discusses the weak cognitive abilities of Indonesian students in higher-order thinking skills such as reasoning, analysis, and evaluation, as evidenced by the results of TIMSS 2015. The study overall emphasized Indonesian students' low critical thinking skills (Rafafy Batlolona et al., 2019).

Therefore, teachers need to know the learning model that can improve students' higher-order thinking skills. By knowing the right learning model, teachers can design effective Learning to develop students' high order thinking skills. An important reason for knowing the learning model that can improve students' high-order thinking skills is to improve the quality of education. High-order thinking skills are one indicator of the quality of education. Therefore, teachers need to know the learning model that can improve students' high order thinking skills. By knowing the right learning model, teachers can design effective Learning to develop students' high order thinking skills. An important reason to know the learning model that can improve students' high order thinking skills is to improve the quality of education. High order thinking skills are one indicator of the quality of education. Therefore, this study will examine several things based on the following problem formulations:

a. What model is most widely used to improve students' high order thinking skills?
b. What model is most widely used to improve students' high order thinking skills based on Disciplines (mathematics and science)?
c. What level of education applies the most learning models to improve students' high order thinking skills?

2. METHOD

The systematic Literature Review (SLR) method is a research method that synthesizes various research results to be presented as more comprehensive and balanced facts. This method is carried out systematically by identifying through predetermined methods. The SLR method aims to find and create research comprehensively by referring to specific questions and procedures that are coherent, transparent, and repeatable at every step.

This study uses the PRISMA (Preferred Reporting Items for Systematic Review and Meta-Analysis) method (Moher et al., 2009). Although PRISMA is a publication standard widely used in medicine and public health, it is still appropriate in this study because it helps formulate straightforward research questions and allows us to conduct systematic searches. In addition, PRISMA minimizes various biases and helps in synthesizing research effectively by requiring a systematic search strategy consisting of four different processes: identification, screening, eligibility, and evaluation of article quality (see Figure 1).

Identification

Identification is a process that involves identifying and diversifying keywords that are appropriate for article searches. Keywords are needed during the search process to improve the article's accuracy. In this study, two main keywords were selected. They are *High Order Thinking Skill*s and *Learning Models*. To diversify keywords, synonyms, related words, and variations of the main keywords were also searched on online sites, previous research keywords, and the Scopus and ERIC databases. Using the selected keywords, article searches were conducted in two central databases: ERIC and Scopus. Both databases were selected based on several advantages. First, databases such as ERIC and Scopus have advantages in comprehensive searches, more stable search results, and more sophisticated search functionality than other databases.

The search technique for articles in these databases (ERIC and Scopus) is an advanced search using essential functions, such as Boolean Operators (AND, OR). Based on the keywords, databases, and search techniques, 175 articles were obtained from the Scopus database and 855 articles from the ERIC database. Of the 1030 articles collected, 363 were excluded because they were duplicates, and 168 were excluded because the title did not describe the use of the learning model. The remaining 499 articles entered the screening stage.

Screening

Screening is a process in which inclusion or exclusion criteria are set to select suitable articles to form a systematic literature review. The first criterion is the year of publication in the last 23 years (2000-2023). The selection of this period is based on several considerations because many related articles have successfully obtained reliable data during this period. Considering that the search in major databases showed a significant spike in publications related to HOTS elements in teaching and learning in 2017 for quality control, only articles published in English were selected to avoid confusion in reading and understanding. Therefore, only articles with relevant empirical data were considered in this study. This study includes inclusion criteria in this process. Inclusion is important to ensure that all selected articles contribute relevant findings to the systematic literature review. This study's selected articles contain findings focusing on learning models that enhance HOTS in teaching and Learning. Therefore, articles on teaching higher-order thinking skills that did not explicitly state HOTS-related learning models were eliminated. After the screening process, 363 articles were eliminated, leaving 136 articles for the following process.

Eligibility

The remaining 136 articles underwent a second screening process, the eligibility stage. The eligibility screening process ensured that all selected articles were relevant and could be used in the SLR. This process was carried out by reading the title and abstract. The methodology, results, and discussion sections were also analyzed if no decision was made after reading the title and abstract. In this process, 43 articles were excluded because the studies conducted were not in mathematics and science. The remaining 93 articles were screened again, and 52 had to be eliminated because the studies were conducted at the undergraduate and/or postgraduate levels. After that, 21 articles had to be excluded again because they were unrelated to their research's learning model. Therefore, at the end of this phase, only 20 articles remained eligible for analysis in the SLR.

Evaluation

At this stage, the remaining 20 articles were analyzed for their metadata regarding the type of learning model used, the level of education of the research sample, and the branch of science used in the research.

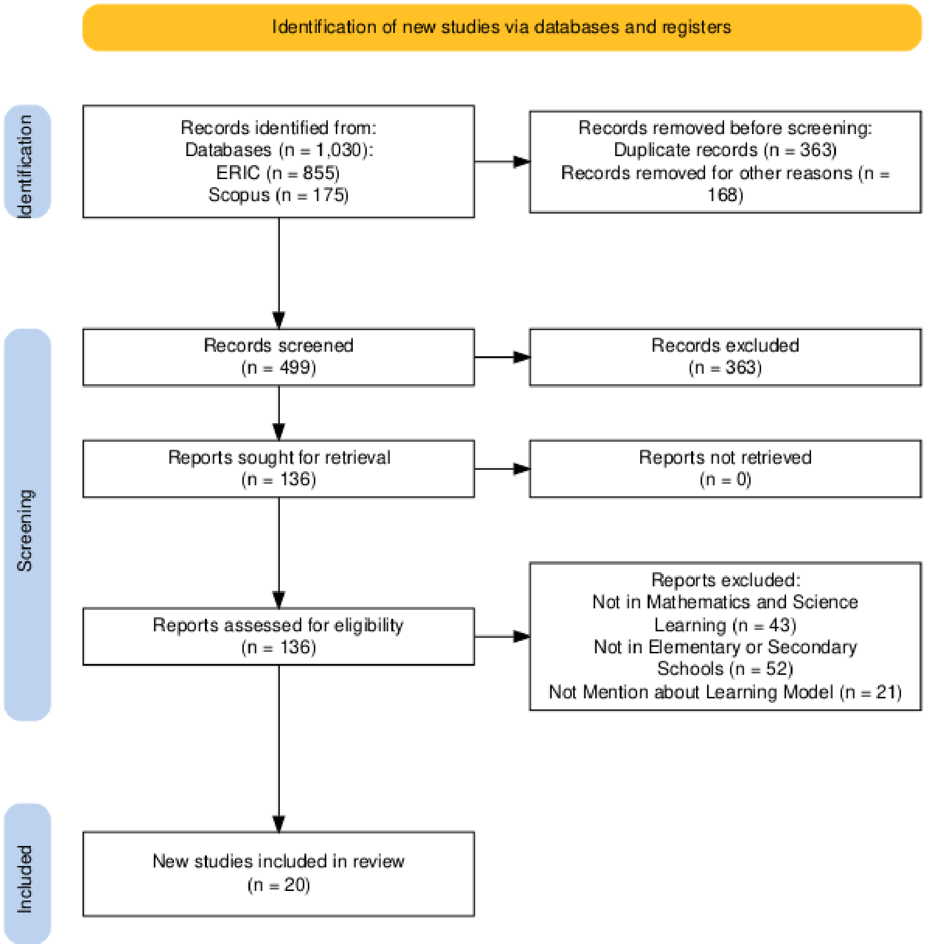

Figure 1. SLR Scheme

3. RESULTS AND DISCUSSION

In this SLR, the inclusion criteria become the eligibility standard in selecting appropriate articles. All articles found in the initial search are examined and assessed using the inclusion criteria so that the data in the research used can be by the research objectives and the literature review conducted is directed and specific. The following are the inclusion criteria in this SLR study: (1) Articles related to improving high-order thinking skills, (2) Articles that use a combination of learning models to improve high-order thinking skills, (3) Research articles related to Mathematics and Science Education, (4) Research subjects consisting of students and teachers in primary and/or secondary school, (5) Research published in the last 23 years (2000-2023), and (6) in English. The exclusion criteria in this article are as follows: (1) Does not discuss HOTS skills, (2) There is no learning model in the abstract, (3) Articles are not in the fields of mathematics and science, (4) Research was conducted on undergraduate and/or graduate program, (5) not in English. Based on the inclusion criteria set, the results are then categorized based on the most appropriate learning model, the effectiveness of using the model, disciplines, and levels of education (see Table 1.)

Table 1. Studies included in the review

No.	Authors and Year	Title	Journal
1	(Abdurrahman et al., 2021)	Improving polytechnic students' high-order-thinking skills through inquiry-based Learning in the mathematics classroom.	Journal of Mathematics Education
2	(Amin & Ikhsan, 2021)	Improving higher-order thinking skills via semi-second life.	International Journal of Science and Technology Education

3	(Avargil et al., 2013)	Challenges in the transition to large-scale reform in chemical education.	Journal of Science Education Reform
4	(Dkeidek et al., 2011)	Effect of culture on students' question-asking ability resulting from an inquiry-oriented chemistry laboratory.	International Journal of Science Education
5	(Hariadi et al., 2022)	Higher-order thinking skills-based learning outcomes improvement with blended web mobile learning model.	International Journal of Learning and Technology
6	(Ibrahim et al., 2020)	Impact of higher-order thinking skills (HOTS) module based on the cognitive apprenticeship model (CAM) on student's performance.	Journal of Mathematics Education
7	(Kurniawan et al., 2021)	The PINTER learning model enhances higher-order thinking and communication skills in algebra.	Mathematics Education Journal
8	(Kwangmuang et al., 2021)	The development of learning innovation to enhance higher-order thinking skills for students in Thailand junior high schools.	Journal of Educational Innovation
9	(Lu et al., 2021)	Understanding the mediating effect of learning approach between learning factors and higher-order thinking skills in collaborative inquiry-based Learning.	Journal of Educational Psychology
10	(Martawijaya et al., 2023)	The effect of applying the ethno-STEM-project-based learning model on students' higher-order thinking skills and misconception of physics topics related to Lake Tempe, Indonesia.	Physics Education Journal
11	(Mitarlis et al., 2020)	The effectiveness of new inquiry-based Learning for improving multiple higher-order thinking skills of prospective chemistry teachers.	Journal of Science Education
12	(Novitra et al., 2021)	Development of an online-based inquiry learning model to improve 21st-century skills of physics students in senior high school.	Journal of Physics Education
13	(Qamariyah et al., 2021)	The effect of implementation of inquiry-based Learning with socio-scientific issues on students' higher-order thinking skills.	Journal of Chemistry Education
14	(Rati et al., 2023)	HOTS-oriented e-project-based Learning: Improving elementary school students' 4C skills and science learning outcomes.	Elementary School Journal
15	(Rusmansyah et al., 2019)	Innovative chemistry learning model: Improving pre-service chemistry teachers' critical thinking skill and self-efficacy.	Journal of Chemistry Education
16	(Samo et al., 2017)	Developing contextual mathematical thinking learning model to enhance higher-order thinking ability for middle school students.	Journal of Educational Research
17	(Cahya Saputri et al., 2019)	Improving students' critical thinking skills in cell-metabolism learning using stimulating higher-order thinking skills model.	Biology Education Journal
18	(Suseelan et al., 2023)	School-type difference among rural grade four Malaysian students' performance in solving mathematics word problems involving higher-order thinking skills.	Journal of Educational Research and Practice
19	(Utami et al., 2020)	Application of two problem-solving cycles to students' higher-order thinking skills on reproductive system material.	Journal of Biology Teaching and Learning
20	(Yerimadesi et al., 2023)	Guided discovery learning-based chemistry e-module and its effect on students' higher-order	Journal of Chemistry

	thinking skills.	Education

The Most Widely Used Learning Models to Improve High-Order Thinking Skills

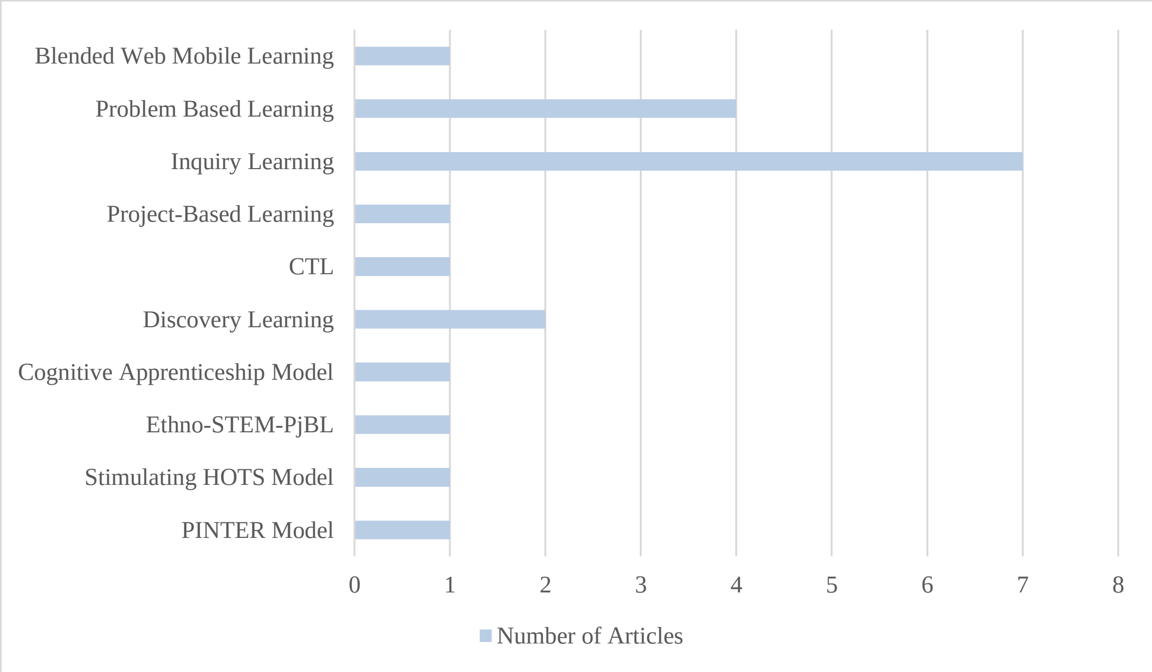

Figure 2. The number of studies with various learning models to improve HOTS

Figure 2 highlights the emphasis on various learning models in educational research focused on higher-order thinking Skills (HOTS). Among all the learning models, IBL (Inquiry-Based Learning) is the most frequently studied, with eight occurrences. This prominence reflects the growing recognition of IBL's role in enhancing HOTS, such as critical thinking, analysis, and problem-solving. Through its student-cantered approach, IBL fosters deeper cognitive engagement, where students actively construct knowledge rather than passively receive information (Holbein et al., 2020). This active engagement is critical for developing the skills needed in complex problem-solving and innovative thinking.

PBL, appearing in four studies, is similarly significant in cultivating HOTS. PBL is known for challenging students with real-world problems that require creative solutions, promoting skills like evaluation, synthesis, and application of knowledge. The collaborative nature of PBL also supports the development of teamwork and communication, essential components of 21st-century skills (Hmelo-Silver et al., 2013). Its strong presence in the studies shows its ongoing relevance in fields where applied knowledge is key, such as mathematics and science.

With two occurrences, Discovery Learning focuses on learner autonomy and exploration, aligning with the development of skills like inquiry and innovation. However, its relatively lower frequency in studies may suggest a preference for models like IBL and PBL, which offer more structured pathways for developing HOTS. While effective for creativity, Discovery Learning's open-ended approach may not always provide the same level of scaffolding needed to achieve great analytical skills (Alfieri et al., 2011). In conclusion, the chart indicates a clear preference for inquiry-driven and problem-solving learning models, which are well-suited for fostering HOTS. As education increasingly shifts towards preparing students for complex, real-world challenges, models like IBL and PBL are at the forefront of pedagogical strategies designed to cultivate critical thinking, problem-solving, and creativity.

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The Most Widely Used Learning Models to Improve High-Order Thinking Skills Based on Their Disciplines

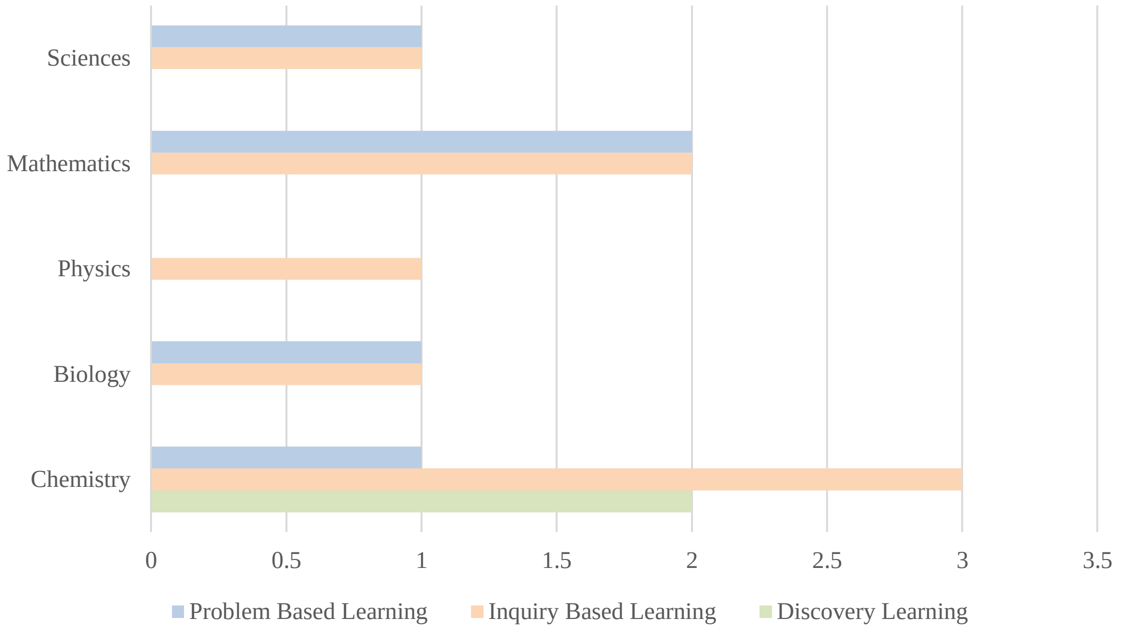

Figure 3. The number of studies with various learning models in the fields of mathematics and science to improve HOTS

Figure 3 illustrates the distribution of articles based on fields of study for the learning models. Discovery Learning, Inquiry-Based Learning (IBL), and Problem-Based Learning (PBL) highlight significant trends in applying these models across various disciplines. Discovery Learning, with two occurrences in the field of chemistry, emphasizes student-driven exploration, where learners are encouraged to investigate problems independently and build their understanding through inquiry. This model is closely associated with fostering HOTS because it requires learners to hypothesize, experiment, and reflect, all essential for developing analytical thinking (Alfieri et al., 2011). In chemistry, Discovery Learning helps students approach problems like real-world scientists, analyzing data and drawing conclusions from their experiments. However, its limited use across other subjects in the table may suggest that while Discovery Learning is effective, it requires careful scaffolding to be successfully implemented, especially in areas where students struggle without direct instruction (Mayer, 2014).

The data shows that Inquiry-Based Learning is the most represented model, appearing in chemistry, biology, physics, mathematics, and science studies. This wide application across disciplines reflects the versatility of IBL in promoting HOTS. In this model, students actively engage with the material by asking questions, investigating solutions, and constructing knowledge, which is critical for higher-order cognition (Jonalyn S. Guerrero & Romiro G. Bautista, 2023). For example, in mathematics, IBL helps students develop problem-solving skills by exploring complex problems and finding multiple solutions, a process that enhances their reasoning and analytical abilities. In science, IBL allows students to test hypotheses and design experiments, further developing their ability to evaluate and synthesize information—key components of HOTS (Gulejova, 2020). The many articles focusing on IBL in different fields suggest that educators across disciplines recognize its effectiveness in fostering skills beyond rote memorization.

Problem-based Learning, as shown in four studies across mathematics, biology, chemistry, and science, has long been associated with developing HOTS due to its focus on solving real-world problems. In PBL, students work in collaborative groups to address complex issues, requiring them to apply knowledge creatively and think critically. This hands-on, practical approach aligns with the demands of HOTS, as students must not only understand the subject matter but also apply it in innovative ways (Spector et al., 2014). In mathematics, for instance, PBL pushes students to move beyond procedural understanding and apply mathematical concepts to solve practical problems.

Translating theoretical knowledge into real-world solutions directly engages skills like analysis, evaluation, and creativity. Similarly, in biology and chemistry, PBL allows students to simulate the work of scientists by designing experiments, analyzing results, and discussing their implications, thus developing critical thinking and inquiry skills (Rasi, 2021).

The result demonstrates that HOTS is a focal point across various subjects when applying IBL, PBL, and Discovery Learning. These models encourage students to engage deeply with content, apply knowledge in new contexts, and approach problems from multiple perspectives, all essential for higher-order thinking. The fact that Inquiry-Based Learning is prevalent across five disciplines suggests that educators recognize its broad applicability in fostering these cognitive skills.

Problem-Based Learning's strong presence in science and mathematics aligns with fields that require practical application and problem-solving. At the same time, Discovery Learning appears to be more niche, particularly effective in subjects like chemistry, where independent investigation can yield significant cognitive growth. However, this limited use across fields may indicate that other models offer more structured support, which is sometimes necessary to effectively develop HOTS.

The data reveals that Inquiry-Based Learning is the most commonly applied model across multiple disciplines, reflecting its versatility in fostering HOTS, followed by Problem-Based Learning and Discovery Learning. Each model's unique approach, whether through independent inquiry, collaborative problem-solving, or guided discovery, aligns with the development of critical cognitive skills required for success in the modern world. The distribution of studies across fields like chemistry, biology, mathematics, and science indicates that educators value these models for their capacity to go beyond surface-level Learning and promote deep, higher-order cognitive engagement.

The Level of Education That Most Often Uses Learning Models That Improve Students' High-Order Thinking Skills

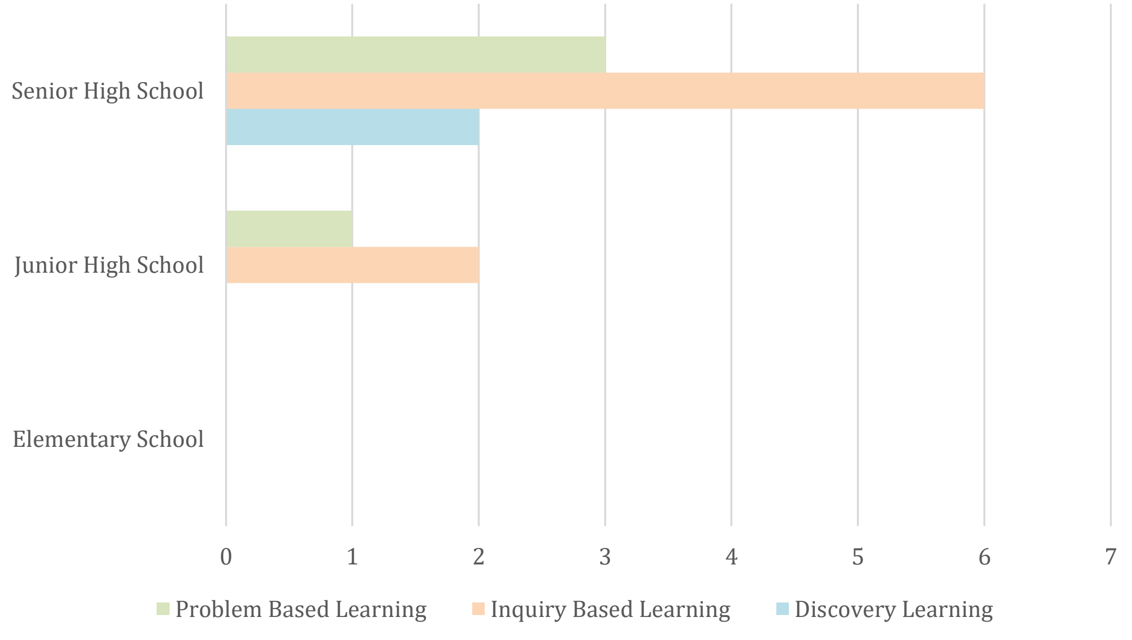

Figure 4. The number of studies with various learning models at educational levels to improve HOTS

Figure 4 shows the distribution of studies based on educational levels for the learning models Discovery Learning, Inquiry-Based Learning (IBL), and Problem-Based Learning (PBL), revealing important insights into how these models are applied across different stages of education. The data reveals that Discovery Learning is applied exclusively at the Senior High School level, particularly in chemistry. This finding aligns with the nature of Discovery Learning, which encourages students to explore, hypothesize, and build knowledge through inquiry. Students are expected to handle more complex tasks at the senior high school level, making it a suitable stage for fostering HOTS through discovery-based methods. Discovery Learning has been shown to help students develop independent thinking and problem-solving skills, as they are tasked with conducting experiments and drawing conclusions based on their observations (Alfieri et al., 2011). However, Discovery Learning's absence at the Junior High and Elementary School levels may indicate that younger students require more structured guidance when learning new concepts. As younger learners often lack the cognitive maturity to engage in fully independent inquiry, they might benefit more from models that provide additional scaffolding to support the development of HOTS (Mayer, 2014).

Inquiry-based Learning (IBL) is present across multiple educational stages, including junior high school and senior high school, with six occurrences in senior high school and two in junior high school. This broad application reflects IBL's flexibility in promoting HOTS at different levels of cognitive development. IBL is known for engaging students in active learning processes that encourage questioning, exploration, and the application of knowledge, which are critical for developing skills like analysis, evaluation, and synthesis (Jonalyn S. Guerrero & Romiro G. Bautista, 2023). In Senior High School, IBL is often used in science and mathematics education, where students must apply theoretical knowledge to real-world scenarios. This is particularly effective for developing HOTS, as students are encouraged to think critically about complex problems, design experiments, and analyze data. In Junior High School, IBL helps students develop these skills by fostering curiosity and allowing them to explore topics through guided inquiry. This gradual shift from guided inquiry to more independent exploration mirrors students' cognitive development as they progress through the education system.

Problem-Based Learning (PBL) appears in both Junior High School and Senior High School, emphasizing the latter more strongly. The application of PBL in senior high school aligns with its focus on engaging students in solving real-world problems, a key factor in developing HOTS, such as critical thinking, problem-solving, and creativity (Spector et al., 2014). Students are mature enough to handle complex, open-ended problems at this stage, working in collaborative groups to find innovative solutions. This hands-on approach is essential for promoting skills students will need in higher education and the workforce (Mayer, 2014). PBL in Junior High School suggests that even younger students can benefit from problem-solving activities that promote HOTS. However, the complexity of problems may be adjusted to match the cognitive level of students at this stage (Habiddin, Herunata, et al., 2022; Munzil et al., 2022; Pertiwi et al., 2021). While the problems may not be as intricate as those presented in senior high school, collaboration and critical thinking still helps students develop the foundational skills needed for more advanced problem-solving in the future.

The distribution of studies across educational levels suggests that as students progress through the education system, they are exposed to increasingly complex learning models that are more effective in fostering HOTS. Inquiry-based Learning is widely applicable across both Junior High School and Senior High School, reflecting its flexibility and effectiveness in promoting critical thinking at various stages of cognitive development. Problem-based Learning is similarly effective, especially in Senior High School, where students are ready to tackle real-world problems that require higher-order cognitive processes. Discovery Learning, while highly effective in promoting independent inquiry, is more limited in its application, likely due to the high level of autonomy it demands from students.

4. CONCLUSION

Based on the systematic review, the study concludes that Inquiry-Based Learning (IBL) is the most frequently used model to enhance students' Higher-Order Thinking Skills (HOTS), especially in science and mathematics education. This model is effective because it focuses on active student engagement, encouraging critical thinking and problem-solving skills. Problem-based Learning (PBL) is also widely applied, particularly in senior high school, where students tackle real-world problems, promoting creativity and deep cognitive engagement. Although less frequently applied, Discovery Learning is effective in fostering independent inquiry, particularly in chemistry education. Furthermore, the review highlights that secondary education, particularly senior high school, most commonly applies these learning models to improve HOTS, reflecting the growing complexity of cognitive tasks as students progress through their education. The study emphasizes the importance of incorporating these learning models into curricula to address the demands of the Fourth Industrial Revolution, preparing students to think critically, analyze complex information, and innovate solutions in real-world contexts.

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