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Enhancing Critical Thinking Abilities in High School Biology: A Systematic Review

Corresponding Author: Md Mirhanuddin

RESEARCH ARTICLE

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Abstract: This research seeks to evaluate the methodologies and strategies employed to improve Higher Order Thinking Skills (HOTS) among high school students studying Biology. The inquiry involved a meticulous examination of 36 scholarly articles contributed by researchers from both Indonesia and other countries, sourced from various digital repositories and online databases. Following the PRISMA-P protocol, the systematic review delved deeply into research design, variables, and approaches aimed at enhancing students' HOTS. Predominant instructional models like Problem-Based Learning (PBL), Inquiry learning, and Discovery learning stood out in HOTS research trends. However, models such as INSTAD and PBI+STAD did not demonstrate significant improvements in students' HOTS. In contrast, alternative learning models, including PBL, inquiry, discovery, Advance Organizer, POE, and BBL, showcased notable enhancements in students' HOTS. Implementing instructional strategies like laboratory activities, mixed methods learning, and utilizing Nutriscore interactive media produced positive results for students' HOTS. Among the 36 articles, two were indexed by SCOPUS, 15 by SINTA, eight were proceedings, nine were theses, and two were unindexed. Furthermore, not all Biology chapters were addressed, with ecosystem and environment, human physiology, fungi, protists, plantae, cell, and biotechnology being the most frequently discussed topics. The articles commonly applied Bloom's taxonomy, with variations that included Marzano's and Gagne's taxonomies.

Keywords: *Higher Order Thinking Skills, Biology Education, Problem-Based Learning, Inquiry learning,*

INTRODUCTION

In 2015, Indonesia ranked 64th out of 72 countries in the Program for International Student Assessment (PISA), a program evaluating literacy skills in reading, science, mathematics, and other competencies of 15-year-old students globally. Subsequently, in 2018, Indonesia dropped to the 73rd position out of 79 participating countries (OECD, 2016, 2018). Consequently, there is a pressing need to take measures to ensure that the skills of Indonesian students remain competitive on the international stage.

To address this challenge, efforts are being made to enhance students' higher-order thinking skills in Indonesia. These endeavors involve the application of appropriate learning models aimed at improving higher-order thinking skills (Directorate General of Teachers and Education

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Personnel, 2018), enhanced assessment methods (Barak & Dori, 2009), improvements in learning resources (Hopson, Simms, & Knezek, 2001), teacher training initiatives (Salirawati et al., 2017), and curriculum enhancements (Putra, Muttaqin, & Setyarini, 2017).

Numerous studies have been conducted to uplift students' higher-order thinking skills. The inaugural research and review article addressing Higher Order Thinking Skills (HOTS) in Indonesia were published in the Journal of Mathematics and Science Teaching in 2001 by Liliasari. The findings indicated that the implementation of HOTS successfully elevated the way science teacher candidates think, covering various stages of critical thinking skills, ultimately enhancing their propositional and combinatorial thinking. The impact suggests that science learning models (MPIPA) are emerging as a contemporary trend in science teacher training for the era of globalization (Liliasari, 2001).

To comprehensively explore the extent of research and application of Higher Order Thinking Skills (HOTS), it is essential to systematically analyze and review research articles addressing HOTS across various proceedings, journals, and theses/dissertations published within a specific timeframe. This systematic review (SR) approach is employed to provide a comprehensive and detailed overview, incorporating methods to minimize bias by identifying, assessing, and analyzing pertinent study outcomes to address specific questions (Petticrew & Roberts, 2005). Research employing SR aims to address specific, relevant, and focused questions (Hariyati, 2010).

The objectives of this study encompass the following: 1) Analyzing learning models and methods based on HOTS, 2) Assessing the instruments used to measure HOTS, 3) Examining the diversity of Biology material covered in HOTS research at the high school level, 4) Scrutinizing the types of learning taxonomies utilized in research on HOTS-based learning, and 5) Analyzing trends in HOTS learning research.

METHODS

Study Design

This investigation adopts a qualitative research approach, specifically employing a document analysis design in the form of a Systematic Review (SR). The SR study adheres to the PRISMA-P protocol, following the guidelines outlined by (Moher et al., 2015). The comprehensive steps in our literature review encompass the selection of the study population. The articles under scrutiny were sourced from an online database, comprising theses of teacher education students, scientific articles published in national journals, proceedings, and international journals. Our research scope is confined to the period between 2001 and 2019. The utilization of Higher Order Thinking Skills (HOTs) as a learning method has gained global recognition and widespread use. The conceptual understanding of HOTs has been present since the early 20th century and was introduced in Indonesia around the 2000s. The substantial application of Higher Order Thinking gained prominence following the implementation of the 2013 curriculum in Indonesian schools, as mandated by the government. The search for relevant literature was conducted on online databases, including Google Scholar, Elsevier-ScienceDirect, Springer, Wiley, and Taylor & Francis Online.

The subsequent sub-step involves establishing criteria for the selection of articles to be utilized. The inclusion criteria are as follows: 1) Selection of documents in either Indonesian or English, 2) Documents that focus on the enhancement of higher-order thinking skills at the senior high school level, 3) Documents employing the keywords "higher-order thinking" and "High School Biology" in their article titles, and 4) Articles published between 2001 and 2019 during

the preparation of this paper. The exclusion criteria are applied as follows: 1) Articles that are not available in their entirety are excluded, and 2) Articles containing only abstracts are also excluded. Following the search process, the collected articles undergo filtering to eliminate duplicate entries, employing the Publish or Perish 7 software. The documents are then filtered based on their relevance to the inclusion and exclusion criteria from the overall search results on each page. Subsequently, the documents that successfully pass the screening process are included in a table for further analysis. The data analysis is conducted through narrative analysis, which involves three stages: data management, intra-article analysis, and inter-article analysis (Petticrew & Roberts, 2005). The schematic representation of this research is depicted in Figure 1. The subsequent step involves data collection, encompassing the extraction of pertinent information from the primary studies. After collection, the gathered data is analyzed through narrative means.

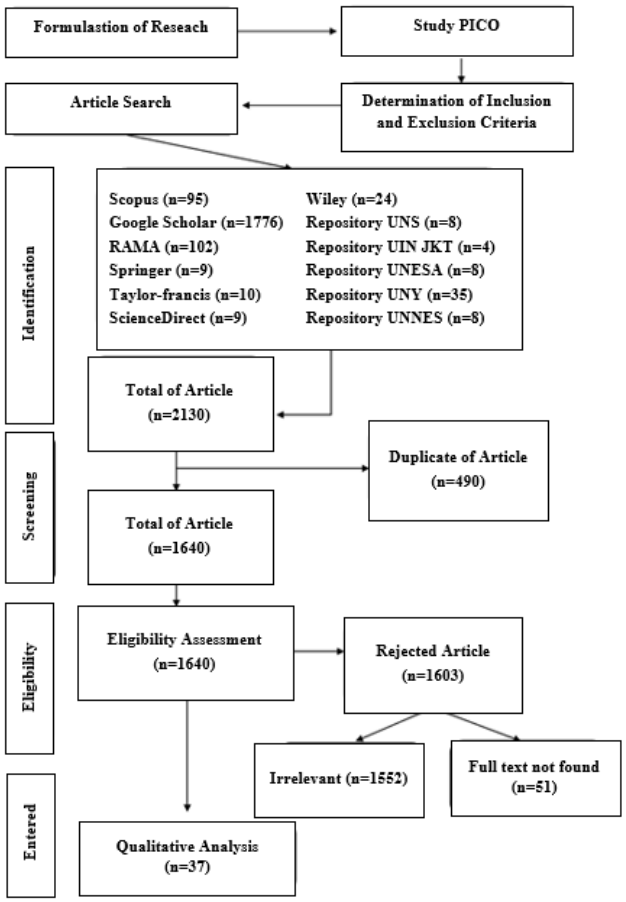

Figure 1. Systematic review flowchart

RESULTS AND DISCUSSION

A total of 2,130 articles from the years 2001 to 2019 were initially identified. Following the duplicate screening process, 1,640 unique articles remained. Subsequently, after applying exclusion criteria, the final set of articles for analysis comprised 36 articles. Among these, 32 articles originated from Indonesian sources, while the remaining 4 articles were of international origin. The collected articles are diverse in terms of indexing, including those indexed in Scopus, the SINTA index (ranging from Sinta 2 to Sinta 6), undergraduate theses, proceedings, and articles that are not indexed. Articles not indexed were scrutinized to verify whether the publisher or journal was associated with predatory practices before inclusion in the review.

Regarding the learning models utilized to enhance students' Higher Order Thinking Skills (HOTS), the review of the selected articles revealed a discussion of various models. Table 1 presents

data on the number of learning models explored in HOTS studies.

Table 1.

Information regarding the quantity of learning models

Data on the number of learning models	**Amount**
Learning Model / Method	
Problem Based Learning	18
Inquiry Learning	5
Discovery Learning	4
Advance Organizer	1
Predict, Observe, Explain	1
Brain Based Learning	1
Group Investigation	1
PBI + STAD	1
INSTAD	1
PBL + Online Interaction	1
Interactive Media	1
Mixed Methods	1
Learning accompanied by practicum	1

A. Problem-Based Learning

As per the examined articles, 18 of them employed the Problem-Based Learning (PBL) model. The PBL model utilized in these articles is based on the frameworks developed by Tan (2009), Arends (2012), and Fogarty (1997). According to Prince & Felder (2007), PBL involves raising various types of problems, including existing problems (real-world issues) and original problems (problems created specifically for educational purposes). In the context of HOTS empowerment discussed in the analyzed articles, the PBL model focused on existing problems, particularly those closely related to students' daily lives, enhancing the contextual relevance of the learning process.

B. Inquiry Learning

Two commonly found types of Inquiry learning models aimed at improving higher-order thinking skills are Guided Inquiry and Free Inquiry. The Inquiry model is believed to enhance HOTS by providing a constructivist-based learning environment that allows students to independently develop their knowledge (Azizah & Prayitno, 2016).

Comparing Guided Inquiry and Free Inquiry, the results indicate minimal differences. The distinction lies in the extent of the teacher's role in the learning process. In Guided Inquiry, the teacher plays a more dominant role as a facilitator, whereas in Free Inquiry, the teacher primarily serves as a supervisor, offering assistance when needed. However, students in Free Inquiry classes demonstrate higher learning independence compared to those in Guided Inquiry classes (Wenning, 2005).

In the analyzed articles, both Guided Inquiry and Free Inquiry models were employed. The Inquiry Model in these articles draws from the frameworks proposed by Scott, Tomasek, & Matthews (2010), and Joyce & Weil (1972).

C. Discovery Learning

The Discovery learning model is recognized for enhancing Higher Order Thinking Skills (HOTS) by allowing students to explore scientific concepts independently. Its application can significantly elevate students' higher-order thinking skills, particularly when leveraging the potential within the school environment to create a more contextual learning experience (Sulastri, 2014). According to student feedback, implementing the Discovery learning model heightened curiosity and self-confidence in the learning process (Riandari, Susanti, & Suratmi, 2018). The articles analyzed in this study adopted the Discovery learning model proposed by Veermans (2003) and Muhibbin (2003).

D. Group Investigation

The Group Investigation (GI) learning model emphasizes student collaboration in the learning process. Considered effective in improving HOTS,

the GI learning model encourages students to rely less on teachers and places greater emphasis on collaborative problem-solving within groups (Nur, 2012). The reviewed articles applied the GI model based on the framework presented by Sharan & Sharan (1990).

E. Advance Organizer

Developed by David Ausubel in 1960, the Advance Organizer (AO) learning model is believed to enhance HOTS by helping students organize and connect their existing knowledge with new information acquired during the learning process (Yuda, 2019). In the analyzed articles, the AO model used was adapted from Downing (1994).

F. Predict, Observe, Explain (POE)

The POE learning model involves stages of Prediction, Observation, and Explanation. Regarded as a model capable of cultivating HOTS, it aids students in formulating hypotheses, conducting experiments, and elucidating experimental results (Suryamiati, Kahar, & Setiadi, 2019). In the analyzed article, the POE model was derived from Ayvaci (2013).

G. INSTAD

In one of the articles (N11), the INSTAD learning model was employed. Combining the Inquiry learning model and the Student Teams Achievement Division cooperative learning model, INSTAD is designed to address the limitations of individual inquiry learning (Evi Nur, Karyanto, & Sugiharto, 2012). The research results indicated that the high-order thinking skills of the treatment class and the control class were not significantly different. Teachers and researchers intending to implement the INSTAD model are advised to optimize learning by adjusting the time allocation.

H. PBI + STAD

In article [N3], the PBI + STAD model exhibits lower outcomes in Higher Order Thinking Skills (HOTS) in the treatment class compared to the control class. Despite being a learning model that fuses problem-based learning and STAD to train students in group work, its effectiveness in enhancing HOTS was not evident in the treatment class. This model is designed to address the weaknesses of both the problem-based learning model and the STAD cooperative model. Successful implementation of the PBI + STAD model requires teacher skills in time management and class organization (Nurjannah, Prayitno, & Ariyanto, 2012).

H. PBL + OI

The learning module based on Problem-Based Learning (PBL) combined with Online Interaction (OI) introduces a modification to traditional PBL by integrating internet-based learning. Seventy-five percent of the learning is conducted face-to-face, while the remaining 25% is allocated for online information sourcing and sharing among students. This model aims to enhance HOTS by fostering active and collaborative learning, encouraging students to develop independent problem-solving ideas (Suwono & Dewi, 2019). In the analyzed article, the PBL + OI model follows the framework presented by Carrió et al. (2011), allocating 80% to PBL-based learning and 20% to conventional lecture-based learning.

I. Brain-Based Learning

The Brain-Based Learning (BBL) model is perceived as effective in training HOTS by incorporating five natural mechanisms inherent in the human brain to optimize its learning potential. These mechanisms include mobility, behavior, knowledge, physicality, and reflection. The BBL learning model underscores the importance of students' readiness to learn and the creation of a positive classroom atmosphere (Hermala, 2019).

J. Learning with Additional Laboratory

Activity

In article [I2], students' attainment of higher-order thinking skills through laboratory learning demonstrated superior results. This approach effectively enhances HOTS as it allows students to utilize various sensory modalities freely during the learning process. The laboratory setting provides the flexibility needed to accommodate diverse student learning models appropriately (Hofstein & Mamlok-Naaman, 2007).

K. Learning with Additional Laboratory Activity

The learning process, complemented by additional laboratory experiments, was formulated by Lee et al. (2014). This approach involves four laboratory sessions conducted within a 24-lesson period in the classroom. Prior to conducting the experiments, students and teachers collaborate to establish hypotheses and determine the materials and tools required for the experiments. Each laboratory session lasts for 45 minutes.

L. Interactive Multimedia

Nutriscore, an interactive multimedia program designed to enhance students' higher-order thinking skills, was implemented in a 2018 study conducted in Malaysia (Research [I4]). Utilizing Marzano's Taxonomy, this multimedia program is rooted in the constructivism learning theory. Nutriscore incorporates various images and video recordings of real learning objects, accompanied by developer-captured illustrations tailored to the material. Additionally, the multimedia features an animated assistant character providing information, mentoring during the learning process, offering motivation, and serving as a study partner. The study revealed a significant difference in the students' skills, with the experimental class outperforming the control class in aspects such as classification and comparison.

HOTS Measuring Instrument.

The data pertaining to Higher-Order Thinking Skills (HOTS) measuring instruments are outlined in Table 5.

HOTS measuring instrument

HOTS Measuring Instrument	Amount
Description	20
Multiple choice	6
Combination	4
Not explained	3
Problem solving test	2
Open Ended Question	1

The Higher-Order Thinking Skills (HOTS) measurement instruments can be categorized into two groups: standardized instruments and those modified by researchers. Standardized instruments are considered superior due to their thorough validation process, ensuring measurement accuracy (Sommers, 2018).

Non-standardized, self-developed instruments may lead to problematic research outcomes, introducing variations between articles. Researchers may opt for self-developed instruments due to limitations in accessibility and cost. Standardized instruments are often in English, posing a challenge for students and researchers to comprehend the content. Additionally, the substantial cost associated with these instruments, approximately 15 million Rupiah for measuring the skills of 30 students per semester, presents a financial obstacle (Sulaiman & Azizah, 2020).

Examples of HOTS assessment questions, as provided in the image from article [N22], encompass both Lower-Order Thinking Skills (LOTS) and HOTS questions. These questions align with Brookhart's (2010) perspective, emphasizing the inclusion of introductory material for student contemplation. HOTS questions should be novel, never previously covered in class, and

specifically designed to gauge higher-order cognitive dimensions. Importantly, the level of difficulty for HOTS measures does not necessarily have to be high.

Material employed in articles focusing on HOTS enhancement covers various biological topics. However, not all materials have been utilized in research on improving HOTS. The material data is summarized in Table 6.

Biological material in HOTS research

Material	Amount
Human Physiology	8
Ecosystem	6
Environment	5
Kingdom Plantae	1
Kingdom Animalia	1
Protists	1
Fungi	2
Biotechnology	1
Not mentioned	2
Cell	1
Nutrition	1

As outlined by Vasminingtya, Sajidan, & Fatmawati (2014), the choice of materials pertaining to ecosystems and the environment is justified by their proximity to daily life, presenting numerous ill-structured problems for students to tackle in the learning process. Additionally, Nikmah, Anggraito, & Widiatningrum (2017) assert that human physiology-related content was selected due to its prevalence in students' everyday experiences, despite being challenging to observe directly. To address this, articles emphasizing human physiology incorporated direct experimental processes, enhancing the contextual teaching of this material.

Regarding the taxonomy of learning, the study's findings indicate that researchers employ various learning taxonomies to conceptualize Higher-Order Thinking Skills (HOTS). Notably, the taxonomies identified in this research encompass Bloom's Taxonomy, Marzano's Taxonomy, and Gagne's Taxonomy, each offering distinct perspectives, as summarized in Table 7.

Bloom's Taxonomy	Marzano's Taxonomy	Gagne's Taxonomy	
Dimensions	**2**	**2**	**1**
Dimension type	Knowledge dimension, Thinking process dimension	Knowledge dimension Processing level dimension	*Variety of Learning*
Focus	Cognitive Aspects	Cognitive, Affective, Psychomotor Aspects	Cognitive, Affective, Psychomotor Aspects
Position of Metacognition	As one part of the dimension of knowledge	As one of the stages of the thinking process	As one of the thinking process

Bloom's Taxonomy holds significant influence in the field of education globally, particularly for shaping curriculum development in the United States. Throughout history, it has played a pivotal role in organizing the teaching and learning processes. Notably, Bloom's Taxonomy has been instrumental in formulating questions for national exams in the United States since the 1970s, contributing to the systematic assessment of educational outcomes (Marzano & Kendall, 2007). In Indonesia, Bloom's Taxonomy serves as a curriculum reference, aligning with Permendikbud nomor 21 tahun 2016 regarding Standar Kompetensi Lulusan (Directorate General of Teachers and Education Personnel, 2020).

Analyzing the articles conducted, it is evident that research trends in Higher-Order Thinking Skills (HOTS) within high school biology learning, particularly in Indonesia, have surged since 2014. This surge coincides with the adoption of the 2013 Curriculum in Indonesia, emphasizing HOTS-based learning approaches for students. Figure 1 illustrates the trends in HOTS research, with a notable focus on learning models endorsed by the Ministry of Education and Culture to enhance students' HOTS, such as Problem-Based Learning (PBL), Inquiry learning, and Discovery learning.

Figure 2 illustrates the trajectory of Higher Order Thinking (HOT) research in high school biology

in Indonesia. The data indicates a rising trend in the adoption of HOT, driven by several factors. Firstly, there have been changes in the education curriculum, emphasizing the cultivation of critical and creative thinking skills. Secondly, there is a heightened awareness of the need to equip students with the skills necessary for success in an increasingly competitive workforce. Thirdly, there is pressure from the business sector and industry to produce graduates capable of critical thinking and problem-solving. Lastly, there is an increasing recognition of the importance of preparing students to be contributing citizens in a complex society (Wardhani, 2018).

CONCLUSION

The findings from the Systematic Review (SR) indicate that the INSTAD and PBI + STAD models did not demonstrate an enhancement in students' higher-order thinking skills. Conversely, models such as PBL, Inquiry, Discovery, Advance Organizer, Group Investigation, BBL, and POE exhibited notable improvements in higher-order thinking skills. Constructivism-based learning, as reflected in these models, appears well-suited for fostering higher-order thinking skills. Furthermore, practices involving learning in the laboratory, mixed methods, and interactive multimedia were identified as effective in enhancing higher-order thinking skills. It is crucial for learning media aimed at improving HOTS to align with learning theories promoting active student engagement, feature appropriate illustrations, and encompass diverse materials.

The instruments utilized across the 36 reviewed articles encompassed both self-developed instruments validated by experts and standardized instruments. These instruments took the form of description questions, multiple-choice questions, open-ended questions, and a combination of various question formats. Questions designed to assess student HOTS typically incorporated introductory material to prompt critical thinking, utilized novel questions not previously covered in class, specifically targeted high-level cognitive dimensions, and did not necessarily entail high difficulty levels.

In terms of research materials, the articles focused on ecosystems, environmental pollution, human physiology, classification, cells, protists, fungi, and biotechnology for HOTS-based investigations. Among the three taxonomies utilized—Bloom's Taxonomy, Marzano's Taxonomy, and Gagne's Taxonomy—Bloom's Taxonomy emerged as the most widely adopted.

Bloom's Taxonomy holds significant sway in the realm of curriculum development, particularly within the United States, and it remains a key point of reference in shaping the Graduation Competency Standards (SKL) under the 2013 curriculum. The surge in Higher Order Thinking Skills (HOTS) research aligns with the adoption of the 2013 curriculum. This research explores various learning models proposed by the Ministry of Education and Culture, among others, aiming to provide insights for gap analysis in HOTS studies and guide targeted initiatives to enhance students' HOTS in the field of biology. Future research endeavors can focus on formulating effective methodologies, educational tools, and assessment models tailored for fostering Higher Order Thinking Skills.

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