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Higher order thinking skills in science learning: a systematic review from 2014-2023

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ABSTRACT

This study presents a comprehensive overview related to higher-order thinking skills (HOTs) as well as recommendations for future study opportunities for educators and researchers. This study uses the systematic literature review (SLR) method to present critically the knowledge, ideas, and findings contained in academic-oriented literature. A total of 276 synthesized papers have been selected from the Scopus database. Annual publication frequency, number of documents, research methods, scope of themes, productive journals and proceedings in research, and learning approaches used in improving HOTs are reviewed. The results show that HOTs in science education have been receiving attention from researchers in the last eight years. Based on the 63 documents reviewed, include HOTs in the title and abstract. Proceedings in the Journal of Physics: Conference Series are the most contributors to publishing HOTs in science education. Quantitative methods are more widely adopted in HOTs research than research and development (R&D), qualitative, mixed, and non-empirical methods. In addition, models of teaching are also the most chosen theme in science education, and the most widely used mobile learning approach to increase HOTs. In the future, this study can become a reference for researchers to consider various solutions to maximize HOTs.

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1. INTRODUCTION

Higher-order thinking skills (HOTs) aim to improve students' thinking skills at higher levels such as the ability to think critically and creatively in receiving various types of information, especially in science learning. However, science is an integral part of the education system to develop an understanding of scientific concepts and prepare students to play a role in a society that is increasingly dependent on science and technology. Therefore, the emphasis on developing higher-order thinking skills has become a major focus in modern science education. HOTs are constantly being discussed in the science education reform agenda. Various countries set aspirational statements about HOTs in the curriculum that students must achieve [1]–[3].

The concept of high-order thinking skills in science learning includes students' abilities to: analyze, evaluate, and apply scientific knowledge critically and creatively [4]–[6]. This involves the ability to think logically, apply scientific methods, and solve problems [7]. Through these skills, students can develop a deeper understanding of science, develop critical thinking skills, and become more actively involved in the

learning process. This is supported by Saido *et al.* [8] who state that it is important for students to develop higher-order thinking in order to have reasoning skills like scientists.

Previous research trends on science learning have placed high-order thinking skills as a priority. HOTS are considered to be very crucial thinking skills needed by teachers to train students to develop 21st century learning [9]–[11]. This is due to changes in future job demands and increasingly complex societal needs. Job descriptions in science and technology increasingly require individuals who have the ability to think critically, solve complex problems, and adapt quickly. In addition, people are also increasingly aware that higher-order thinking skills are important in dealing with global issues such as climate change, energy crisis, and health. Therefore, the development of higher-order thinking is needed as a regular science teaching material in schools to introduce constructivist pedagogy elements into science classes [12]–[14].

Studies related to HOTs in science learning are still documented today. This was proven by Agussuryani *et al.* [15] who conducted a literature review on Google Scholar and Scopus which were published from 2016 to 2020. They explored science, technology, engineering, and mathematics (STEM) integration patterns in growing HOTs. In addition, Hamzah *et al.* [16] reviewed 252 articles published from 2017 to 2021. This study analyzed the elements of the metacognition-based HOTs learning module in schools. The result shows that the increasing HOTs publications number in science teaching requires a systematic synthesis. The current review is intended to complement previous literature studies on HOTs in science learning which is only until 2021.

In the future, studies related to research trends on HOTs can help researchers and educators understand the development of research patterns in this scope and then discover future research opportunities. Therefore, this study analyzes the current status and provides a broad overview of HOTs research from 2014 to mid-2023. Restricted articles published by Scopus-indexed journals are identified to achieve this goal. Scopus is a bibliographic database covering various disciplines which also includes the field of education. Scopus is managed by Elsevier, a leading academic publishing company. Based on the Scopus database, there are no studies that present research directions and developments related to HOTs systematically until mid-2023. Therefore, this study provides a comprehensive and accurate view of HOTs as well as recommendations for future research. This study presents a comprehensive view based on Scopus-indexed articles from 2014 to mid-2023 related to HOTs according to the research questions posed including: i) What are the annual research trends related to HOTs?; ii) Which journals and proceedings contribute the most publications related to HOTs?; iii) How diverse are the research methods used?; iv) What is the scope of the themes in the article?; and v) What learning approaches are used to improve HOTs in science learning?

2. METHOD

2.1. Research design

This study uses the systematic literature review (SLR) method to analyze published articles related to HOTs. The stages of the SLR method are identification, evaluation, and interpretation of all relevant research results related to certain research questions, and topics or phenomena of concern [17], [18]. Therefore, before carrying out the initial stage, researchers searched for related HOTs articles from the Scopus database from 2014 to mid-2023. Search articles using keywords or terms including: “higher order thinking skills” and “HOTs”. Identification of titles, abstracts, and keywords manually has been done to ensure that the target papers are relevant to the research objectives. The selected sample papers are limited to science education.

2.2. Inclusion criteria

Specific criteria are defined to determine which documents fall into the categories for analysis. Inclusion criteria are the desired sample criteria based on research objectives [19]. Therefore, this study sets the following criteria: papers must be in English and published in journals or proceedings from January 2014 to June 2023. Other criteria (book or book chapters, editorial materials, and corrections) are not included.

2.3. Data analysis

Data analysis is data processing that aims to find useful information [20]. This process includes grouping data based on their characteristics, cleaning, transforming, and creating a model to find important information from the document. Based on the initial categorization, there are 276 papers that appear according to keywords. The next process is to re-check each paper and document to ensure that the paper meets the criteria and there are no duplications. The process of determining articles for review is done by checking the title, abstract, and full text. This analysis involves two reviewers in a group discussion to obtain valid articles according to the criteria. The results of the data screening found 213 articles that were not in accordance with the topic being analyzed so they were excluded.

2.4. Relevance evaluation

After obtaining the appropriate papers, the researcher read the full text of all papers. The researcher conducted a review to determine the manuscript's relevance to the research question. This is an accurate and comprehensive systematic review. If there is any doubt whether the document meets the inclusion criteria, the researcher will carry out an independent evaluation [21]. As a result, 63 papers met the inclusion criteria and were selected and reviewed in more depth. All final paper samples were identified according to the research objectives.

3. RESULTS AND DISCUSSION

This study collects data through the identification and evaluation of papers related to HOTs (from 2014 to mid-2023) and then describes them according to the objectives. The included papers were searched with certain keywords and selected with inclusion criteria to be considered in the analysis. Determining appropriate keywords related to HOTs is very important to get relevant and quality papers.

3.1. The annual research trends related to HOTs from 2014 to mid-2023

HOTs refer to the ability to analyze, synthesize, evaluate, and be creative. In the learning science context, HOTs are very important because it is often applied to develop deep conceptual understanding [22], [23], problem-solving [24], and critical thinking skills in science [25], [26]. Generally, HOTs exceed conventional levels of thinking related to remembering facts or basic information. In addition, HOTs also involve deeper understanding and creativity to solve problems, make decisions, and formulate new concepts.

Research developments on HOTs (from 2014 to mid-2023) in science education have varied over time. This is due to increased interest in developing teaching and evaluation strategies that encourage students to use HOTs. Many studies and publications are related to learning approaches that encourage HOTs development [27], [28], using technology in science learning [29]–[31], and evaluating students' HOTs [32]. The research developments related to HOTs are shown in Figure 1.

Figure 1 shows that from 2014 to 2018, the number of HOTs papers in science education has fluctuated. The peak of publication occurred in 2019, and most of them were proceedings (n=10) and journals afterwards (n=4). However, there has been a decrease in publications related to HOTs in science learning in 2022. This is possible because there has been a shift in the research focus of science learning in each country, such as focusing on teaching science that is socially responsive. It places an emphasis on considering students' cultural background, language, and social context in science learning designs. Especially in 2023, it is still possible for an increase/decrease until the end of the year. However, it is possible that HOTs research in science will increase due to the influence of technological developments. Technologies such as: simulation, digital-based learning, and virtual reality can facilitate students' higher-order thinking skills to be successful in the future.

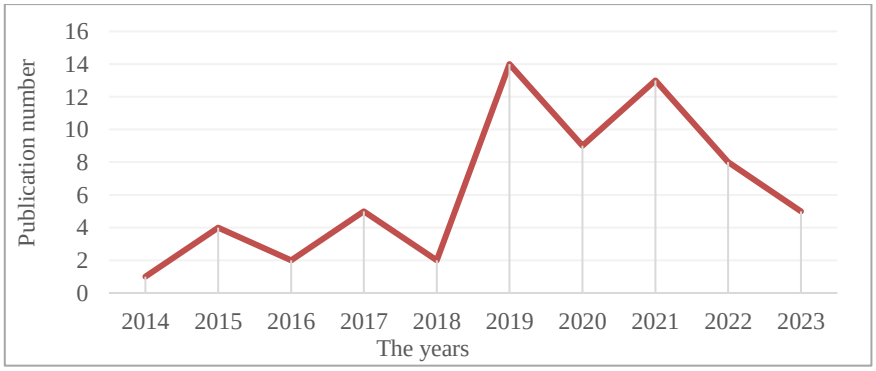

Figure 1. Publications number related to HOTs in science learning

3.2. Journals and proceedings contribute the most publications related to HOTs

The review results of 63 documents found that proceedings contributed more than journals in publishing HOTs. The search results show that there are 27 journals and proceedings that have been published related to HOTs. There are two proceedings that publish the most regarding HOTs from 2014 to mid-2023. Table 1 presents a comparison of publications numbers between proceedings and journals from 2014 to mid-2023.

Table 1. Publication distribution in HOTs-related journals and proceedings from 2014 to mid-2023

No	Journals and proceedings	Papers (N)	Percentages (%)
1	Journal of Physics: Conference Series	22	34.92
2	AIP Conference Proceedings	13	20.63
3	International Journal of Instruction	2	3.17
4	Jurnal Pendidikan IPA Indonesia	2	3.17
5	Universal Journal of Educational Research	2	3.17
6	Chemistry Education Research and Practice	1	1.59
7	Advanced Science Letters	1	1.59
8	Education Research International	1	1.59
9	Eurasian Journal of Educational Research	1	1.59
10	European Journal of Educational Research	1	1.59
11	International Journal of Advanced Computer Science and Applications	1	1.59
12	International Journal of Evaluation and Research in Education	1	1.59
13	Journal for the Education of Gifted Young Scientists	1	1.59
14	Journal of Advanced Research in Dynamical and Control Systems	1	1.59
15	Journal of Science Education and Technology	1	1.59
16	Journal of Technology and Science Education	1	1.59
17	Journal of Turkish Science Education	1	1.59
18	Jurnal Pengukuran Psikologi dan Pendidikan Indonesia	1	1.59
19	Man in India	1	1.59
20	Perspectives and Practices of Gamification	1	1.59
21	Procedia-Social and Behavioral Sciences	1	1.59
22	Canadian Journal of Science, Mathematics and Technology Education	1	1.59
23	Educational Research and Reviews	1	1.59
24	International Education Studies	1	1.59
25	IEEE Conference on e-Learning, e-Management and e-Services	1	1.59
26	International Journal of Instruction	1	1.59
27	Eurasia Journal of Mathematics, Science & Technology Education	1	1.59
	Number of publications in journals	27	42.9
	Number of publications in proceedings	36	57.1
	Total	63	100

Table 1 displays 63 documents that have been analyzed. Based on the analysis, it shows that HOTs publications in the Journal of Physics: Conference Series amounted to 34.92% and AIP Conference Proceedings 20.63% were the most contributions. This was followed by the International Journal of Instruction (3.17%), the Indonesian Science Education Journal (3.17%), and the Universal Journal of Educational Research (3.17%). Journals and other proceedings each contributed (1.59%). In general, it was found that most of the HOTs papers in science learning were published through proceedings, which accounted for 57.1% of the total publications in the last decade. Several factors may explain why proceedings often publish more articles than journals in some contexts. These factors are the publication type, the review process, and the focus on new and innovative research.

Proceedings tend to be more related to scientific conferences or meetings, where researchers can submit papers or abstracts to be presented in academic forums. Conferences often encourage broad participation and allow researchers to share their latest findings or preliminary research. Therefore, proceedings tend to receive more articles to facilitate the exchange of information among conference participants.

The peer review process in proceedings is more concise than in scientific journals. Proceedings are usually published at a shorter time after the conference. As a result, reviews may be performed more quickly and, in less detail, than journals. Proceedings often draw preliminary research, recent findings, or research that focuses on emerging fields. Scientific journals tend to have a higher standard of scientific significance, originality, and contribution. Therefore, some of the research presented in the proceedings may not have gone through a full development process and may not meet the journal's strict criteria. While proceedings can be a valuable information source in terms of the latest research developments, it is important to remember that articles published in journals that go through a rigorous review process tend to have higher levels of validity and reliability. Therefore, it is important to balance the information from both types of publications to get a more comprehensive overview of a particular topic.

There are 27 journals and proceedings that publish papers with the title "HOTs in science learning" in their papers. Proceedings contributed the most in published papers on HOTs, while many studies reveal the order of journals about HOTs without involving proceedings. Supeno *et al.* [33] stated that there were 10 literatures related to HOTs published in journals obtained from several data such as the Garuda Portal, Google Scholar, and DOAJ with a time range of the last 5 years (2016-2020). In addition, a journal analysis on HOTs was also carried out with the number of research articles in physics learning from 2016-2021 indexed by Google Scholar experiencing the highest increase in 2017 [34], [35].

3.3. The diversity of research methods related to HOTs

The diversity of research methods related to HOTs in science learning reflects the various approaches used by researchers to investigate and understand how HOTs can be developed and applied in the learning science context. Several research methods commonly used are shown in Figure 2. The figure shows the most widely used quantitative approach. Sequentially, the research methods frequency that has been analyzed from 2014 to mid-2023, quantitative research has the highest frequency than research and development (R&D), qualitative, literature review, and mixed. This diversity of research methods helps researchers and educational practitioners to understand the complexity and effectiveness of various learning approaches that focus on developing HOTs in learning science.

Each research method has its own advantages and uses. These advantages are quantitative research allows the research results generalization to a wider population using a representative sample. Whereas qualitative research allows an in-depth understanding of complex phenomena and special contexts. The mix-method allows in-depth data mining through a qualitative approach and also provides empirical data support through a quantitative approach. Meanwhile, R&D focuses on developing practical and innovative solutions to problems encountered in real-world contexts. In addition, in the literature review, it is possible to gain a thorough understanding of the topic under study and find trends or knowledge gaps in the field. It is important to remember that each type of research method has its own limitations and scope. The selection of the right method depends on the research questions, research objectives, and the characteristics of the phenomenon to be studied. In many cases, researchers may also combine several methods to gain richer and more comprehensive insights.

The results show that the quantitative method is most often used by HOTs researchers in science learning. However, apart from being quantitative, the number of papers using R&D was also consistently used from 2017 to mid-2023. Consideration of using more quantitative methods is possible because the use of a representative sample allows the researcher to make generalizations about the wider population, uses careful statistical analysis to process the data, avoids overly subjective interpretations, and allows the researcher to gain a clear understanding of the phenomena being studied. The quantitative method is the most frequently used [36]–[40]. Other research also revealed that of the 6 articles analyzed, those from journals and proceedings that were most widely used were quantitative [41].

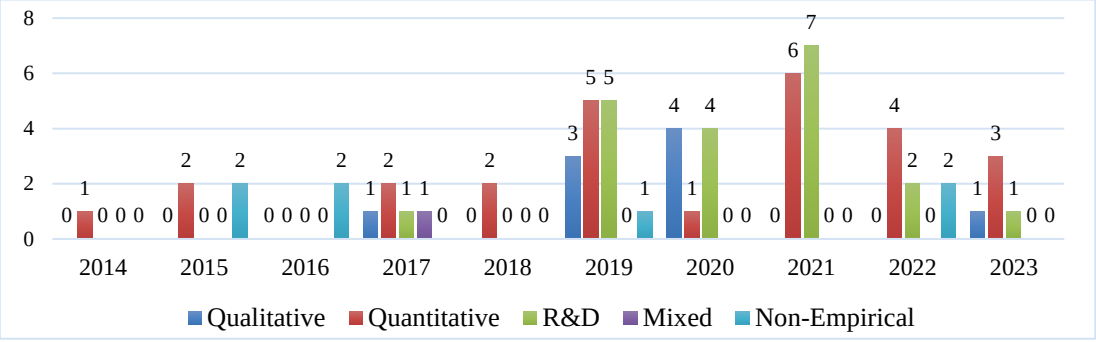

Figure 2. The research methods diversity related to HOTs in science learning

3.4. Scope of themes in articles

The diversity of research themes and scopes related to HOTs reflects the complexity and importance of developing HOTs. HOTs are thinking skills that involve more complex cognitive processes, including analysis, synthesis, evaluation, and creativity [42], [43]. Through the diversity of themes and research scopes of publications related to HOTs, a more comprehensive insight into the challenges and opportunities in the development of HOTs is obtained. These studies have great potential to advance education and help create a generation that is more skilled, creative, and critical thinkers in the face of a rapidly changing world. Several research scopes and themes related to HOTs from 2014 to mid-2023 are shown in Table 2.

The development of HOTs is considered crucial because it can help students overcome complex problems, make decisions, and succeed in a dynamic and changing environment [44]. The importance of developing HOTs in education has attracted the attention of researchers, educators, and educational practitioners. In line with developments in education and research, various themes and research scopes related to HOTs have emerged to explore the potential, challenges, and implications of HOTs in various aspects of education. Based on Table 2, the themes of "model of teaching" and "assessment and evaluation" are the most papers, while the themes of "curriculum development" and "distance learning" are the fewest.

Table 2. The scope of themes related to HOTs research in science learning

Scope	Papers	Percentages (%)
Models of teaching	23	36.51
Assessment and evaluation	20	31.75
Multimedia	11	17.46
Learning resources	4	6.35
Teacher professional development	3	4.76
Curriculum development	1	1.59
Distance learning	1	1.59

The scope of "models of teaching" is more preferred. This scope description includes the use of a scientific video-animation approach [45], learning with an inquiry approach [46], [47], collaborative learning, and being able to apply their knowledge in everyday life [48], and project learning [49]. Other studies also reveal that socio-scientific issues are used as learning strategies in the classroom to improve students' higher-order thinking skills [50]. To increase HOTs, learning needs to be oriented toward developing various learning media, learning materials, learning models, and strategies [51]. The next most extensive theme is "assessment". The theme of "assessment" has been developed to measure HOTs [52]. Other themes based on current research seem to be rarely of interest to HOTs researchers. This is an opportunity for educators and other researchers to conduct studies in the future. Apart from that, researchers and education can research within the scope of "models of teaching" with other learning approaches.

3.5. Learning approaches to increase HOTs in science learning

Appropriate learning approaches can help improve HOTs in science learning. These learning approaches can be adapted to the needs and characteristics of students and learning materials. By using appropriate learning approaches, educators can help students develop the HOTs needed to succeed in complex and dynamic environments. Table 3 presents the findings of several learning approaches in articles to improve HOTs from 2014 to mid-2023.

Table 3. Learning approaches used to improve HOTs

Learning approaches	Papers (N)	Percentages (%)
Mobile learning	5	21.74
STEM-based learning	4	17.39
Laboratory-based learning	3	13.04
Inquiry learning	3	13.04
Problem-based learning	2	8.70
TPACK-based learning	1	4.35
Contextual learning	1	4.35
Project-based learning	1	4.35
Discovery learning	1	4.35
Socioscientific issue-based learning	1	4.35
Mind Mapping Learning	1	4.35
Total	23	

The results of the review obtained 23 out of 63 papers that focused on approaches to improve students' HOTs. Based on these papers, then it is analyzed what learning approaches are used to improve HOTs in science learning. There are 11 approaches that can be used to improve HOTs. Table 3 is the approach strategy used in improving students' HOTs in science learning. This study found that the "inquiry learning" and "problem-based learning" approaches were dominantly applied to improve students' HOTs. Although this learning approach can improve HOTs, growing them requires time, discipline, and a supportive environment.

This comprehensive literature study provides directions for researchers and educators to conduct research related to HOTs in science learning in the future. This study shows that there is an increase in the number of publications about HOTs in science learning every year. The results of this study are in line with the results of Khoeriah *et al*. [53] who found that there were around 100 publications related to HOTs between 2015 and 2021. In addition, from 2016 to 2020 on Google Scholar and Scopus (Database: Elsevier, Scopus, and ScienceDirect) 18 articles were indexed by Google Scholar, and 20 articles were indexed by Scopus. HOTs research trends from 2016-2020 increased the most in 2020 [15]. Through the Web of Sciences (WoS) database and Scopus, there are 252 HOTs articles from 2017 to 2021 [16]. This shows that HOTs research is increasing every year.

The most widely used learning approach to improve HOTs in science learning is mobile learning. Mobile learning is able to improve student HOTs [54]. In addition, a general analysis of the relevant literature in peer-reviewed journals and conference proceedings published between the 1990s and 2019 also explains that mobile learning facilitates the development of HOTs. Through mobile-based learning, it can make a positive contribution to students' higher-order thinking skills [55]. In addition, HOTs can be improved through STEM, problem-based learning, project based learning, inquiry, contextual learning, and collaborative learning [56]–[59]. In this study, it was also found that teaching HOTs requires consistency and patience. Students may need time to develop these skills, so it is important to provide ongoing support and teach effective strategies for thinking critically and creatively. This is supported by Zohar [60] that in teaching HOTs, there is a tendency to prioritize values not processes, so involvement in the development of professional knowledge from educators is required.

4. CONCLUSION

A review of 63 papers published from 2014 to mid-2023 related to HOTs in science learning, shows that there is a tendency to increase every year. The highest number of articles were published in 2019 and 2021. It was also stated that the most productive proceedings in contributing to HOTs publications in science learning were "Journal of Physics: Conference Series" (n=22) and "AIP Conference Proceedings" (n=13). Within a decade, the research methods most widely used in HOTs research in science learning were quantitative, R&D, qualitative, literature review, and mixed. Furthermore, the scope of the theme most often used is "models of teaching". Finally, mobile learning is a learning approach that is widely used by researchers to improve HOTs in science education. This result can serve as a reference for educators and policymakers in designing more effective curricula and learning strategies to integrate HOTs into science education, preparing students for a future filled with intellectual and technological challenges. However, science education that focuses on HOTs can help students develop a deeper understanding of science, critical thinking skills, and better preparation for a future that involves science and technology.

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