Biology Learning Research Trends Based on Quantitative Literacy to Improve Higher Order Thinking Skills: A Literature Review

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Abstract Empowerment of higher-order thinking skills is one of the goals to be achieved in 21st century learning. Learning in biology has led to quantitative data that requires reasoning and analysis to understand it. This literature review aims to discover trends in quantitative literacy-based learning research to increase HOTS. The research method used is a systematic literature review of several reputable articles published in recent years through content analysis. Based on the 16 papers used in this review, it was found that there was a tendency to increase research variation in various methods. This study also shows that ecological material is the most widely used topic in research related to quantitative literacy, both at the high school and university levels. Concerning the findings of this study, several recommendations have been put forward for future research that underpins quantitative literacy as the main focus in increasing HOTS. Some of these recommendations include increasing the variety of types of research and choosing a more diverse biological topic.

Keywords: Quantitative literacy, Higher-order thinking skills, Biology learning

INTRODUCTION

Science is experiencing a broad cognitive revolution in various fields. In the 21st century, science has led to quantitative literacy (Olimpo et al., 2018; Soule et al., 2018). All aspects of human life are inseparable from Science and Technology, which contains information from graphs, tables, and other statistical data (Flanagan & Einarson, 2017).

The use of information and communication technology in education has also undergone several paradigm shifts since the use of diusageal learning applications (Chee et al., 2018; Isnaeni et al., 2021). Furthermore, experts are increasingly analyzing quantitative data sets of long-term and high-frequency sensors as part of research, and it is hoped the next generation will also have this capability (Klug et al., 2017). For this reason, quantitative literacy skills are needed to understand these data.

In line with the development of biology, the demand for mastery of biological literacy is increasing (Senisum et al., 2022). Physical literacy is not only in qualitative data but also in quantitative form. Through biological litphysicaldents focus on using critical conceptfundamentallyllogy to make decisions in solving problems through scientific investigation (Suwono et al., 2017). Unfortunately, learning activities, especially in Indonesia, are still teacher-centered. This situation causes the mindset of students included in quantitative literacy to be limited and students' understanding of biological concepts luckiness to be improved, so critical thinking skills still need strangers; textbooks and modules with few pictures still dominate biology learning in schools (Isnaeni et al., 2021).

Recent trends in curriculum development and teaching methods include the need to shift from teaching to learning (Alsarayreh, 2021). The use of collaborative learning models and strategies can help students learn through communication and interaction between them and the teacher (Chee et al., 2018). Educational institutions are needed to prepare students who are competent and able to compete globally (Hujjatusnaini et al., 2022; Wikanta & Susilo, 2022). For this reason, the role of the teacher is needed to encourage students to maximize their thinking skills, especially in the learning process.

Learning biology involves skills and reasoning (Amoah et al., 2018). Several reports highlight the increasingly quantitative nature of biological research and the need to innovate. The report emphasizes the quantitative nature of biology and the need for students to be able to apply mathematical concepts and models to formally describe complex biological phenomena (Stanhope et al., 2017). Critical thinking skills are needed to explain and solve problems. This skill is one part of the Higher Order Thinking Skills. HOTS can be trained by familiarizing students with working with quantitative data to analyze, visualize, and interpret data (Klug et al., 2017; Soule et al., 2018).

From the literature study, it is known that quantitative literacy is important to be trained to increase students' HOTS. This is because students need to be accustomed to maximizing the thinking abilities their thinking abilities reviews using content analysis in several scientific journals, in detail this research is intended to answer the following questions: 1) What are the trend and the number of quantitative literacy research publications in increasing HOTS from year to year?, 2) What are the research subjects of literacy research?, 3) What implementations are provided to increase HOTS through quantitative literacy? 4) What topics or biology materials are often used to investigate HOTS based on quantitative literacy?, and 5) How does quantitative literacy have the

potential to increase HOTS? Studying these various aspects can be an illustration of learning biology to increase students' HOTS through quantitative literacy.

METHOD

This review was carried out systematically according to the Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) guidelines developed by Page et al. (2021). The method used is a systematic literature review by analyzing relevant international articles and focusing on quantitative literacy to increase student HOTS, both at the high school and tertiary levels. The types of articles used in this literature review were obtained using Harzing's Publish or Perish software using Scopus and Google Scholar database media by entering several keywords, namely quantitative literacy, HOTS, and critical thinking. The search resulted in 203 articles. After being selected, 16 indexed articles (Q1-Q3) were obtained from 2017 to 2023 that match the topics discussed. The stages of the article selection process through the PRISMA guidelines are explained in Figure 1 below.
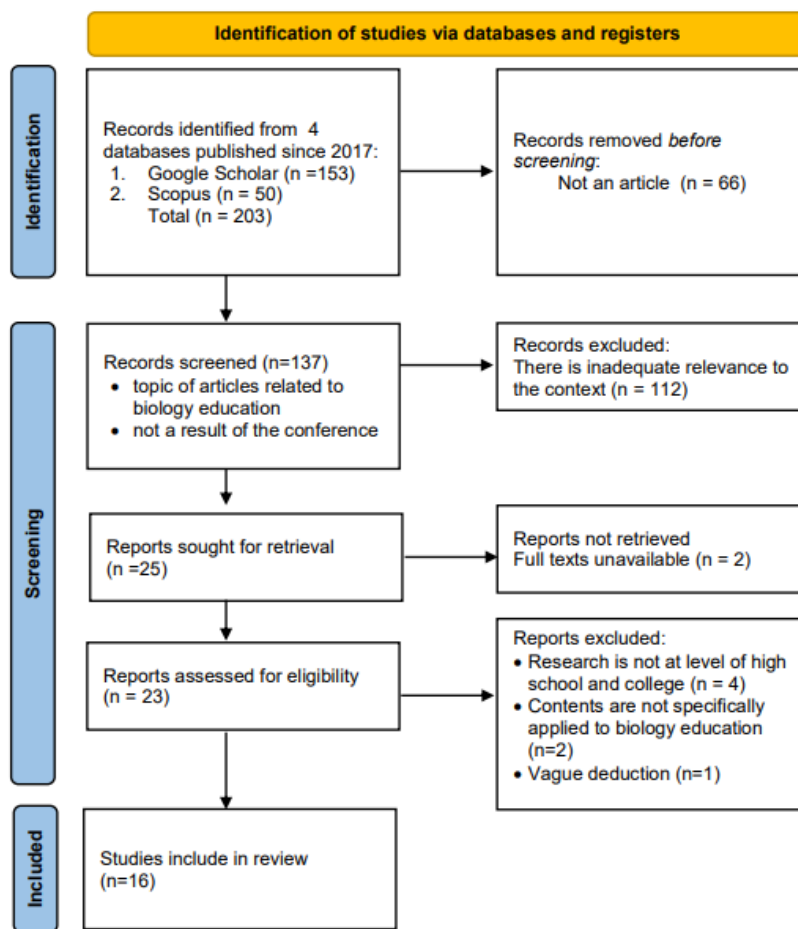
Figure 1. PRISMA source search process flowchart.

FINDING AND DISCUSSION

Research Trends and Number of Publications

Based on the results of a literature review search, 16 articles obtained through the PRISMA guidelines were analyzed. The results of an empirical study related to the article are presented in Table 1 below.

Table 1. Empirical study of quantitative literacy research and HOTS.

No	Author	Journal Name	Publisher	Country	Research Method	Research Content
1	Alsarayreh R., S. (2021)	Cypriot Journal of Educational Sciences	Birlesik Dunya Yenilik Arastirma ve yayincilik Merkezi	Cyprus	Quasi experiment	Active learning strategies
2	Chee, et al. (2018)	Int. J. Mobile Learning and Organisation	Inderscience Publishers	Switzerland	Quasi experiment	The effectiveness of learning media (applications)
3	Sung, et al. (2020)	Journal of Biological Education	Taylor and Francis Ltd.	United Kingdom	Qualitative Descriptive	Quantitative literacy learning strategy
4	Stanhope, et al. (2017)	CBE—Life Sciences Education	American Society for Cell Biology	United States	Research and Development (RnD)	Assessment (*Quantitative Reasoning Exam*)
5	Isnaeni, et al. (2021)	Jurnal Pendidikan IPA Indonesia	Universitas Negeri Semarang (UNNES)	Indonesia	Qualitative Descriptive	Critical thinking learning media
6	Klug et al. (2017).	Ecosphere	Wiley-Blackwell	United States	Quasi experiment	Quantitative literacy learning models and media
7	Soule et al. (2018).	Journal of Geoscience Education	National Association of Geoscience Teachers Inc.	United States	Quasi experiment	Quantitative literacy learning media
8	Suwono, et al. (2017)	Jurnal Pendidikan IPA Indonesia	Universitas Negeri Semarang (UNNES)	Indonesia	Quasi experiment	Biological literacy learning model and critical thinking
9	Flanagan & Einarson (2017)	CBE Life Sciences Education	American Society for Cell Biology	United States	Correlational	Quantitative literacy related to gender, math confidence, and grit
10	Olimpo, et al. (2018)	Journal Of Microbiology & Biology Education	American Society for Microbiology	United States	Mixed-Method	Statistical reasoning and quantitative literacy
11	Ardiansyah, R. & Diella, D. (2022)	Jurnal Pendidikan IPA Indonesia	Universitas Negeri Semarang (UNNES)	Indonesia	Deskriptive: Survey	Quantitative literacy skills

N o	Author	Journal Name	Publisher	Country	Research Method	Research Content
12	Hujjatusnai ni, N., et al. (2022)	Jurnal Pendidikan IPA Indonesia	Universitas Negeri Semarang (UNNES)	Indonesia	Mixed-Method	Learning model-HOTS
13	Senisum, M., et al. (2022)	Education Sciences	MDPI AG	Switzerland	Quasi experiment	Learning model-critical thinking
14	Fitriani, et al. (2020)	International Journal of Instruction	Gate Association for Teaching and Education	Turkey	Quasi experiment	Learning model-critical thinking
15	Wikanta, W. & Susilo, H. (2022)	International Journal of Instruction	Gate Association for Teaching and Education	Turkey	Deskriptive : Case Study	Learning model-HOTS
16	Saenab, S., et al. (2020)	Education Sciences	MDPI AG	Switzerland	Research and Development (RnD)	Learning model-critical thinking

The results of the empirical studies in Table 1 show that the research methods related to quantitative literacy in efforts to increase HOTS in several countries are very diverse. This study used quasi-experimental methods (n=7), mixed methods (n=2), RnD methods (n=2), qualitative descriptive methods (n=2), descriptive survey methods (n=1), case study descriptive method (n=1), and correlational method (n=1). Each method used is adjusted to the research content under study. The distribution of the research methods used each year in the 16 articles is presented in Figure 2 below.
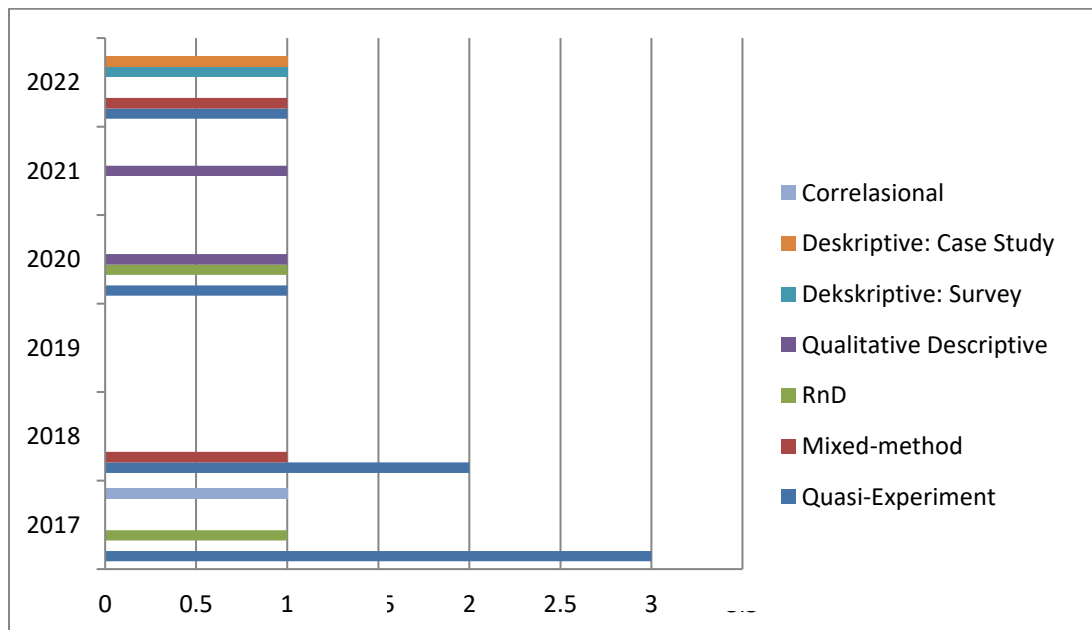
**Figure 2.** Distribution of research methods used by year.

The diagram above illustrates that the use of quasi-experimental research methods is most widely used by researchers almost every year. The high frequency of using this

research method compared to others explains that the researchers chose the treatment that best suited their educational concerns. In general, the researchers attempted to compare several research methods in empowering quantitative literacy skills to increase student HOTS. On the other hand, the true-experimental research method, which is said to be the most challenging design to apply to educational problems, is not found in publications that highlight quantitative literacy.

Since 2017, the analysis of articles with this type of quantitative research has been more widely used. In 2022, research methods will be increasingly varied, such as using qualitative research methods such as case studies and surveys. The trend of qualitative research has been shown to start increasing and targeting educational research. Such conditions are closely related to the advantages of a qualitative approach to define a phenomenon in detail and comprehensively. However, it is still limited to RnD and correlational research in recent research. The lack of existence of this research is an excellent opportunity for future researchers to use this research method and focus their research on quantitative literacy.

Research Subject

Empowerment of higher-order thinking skills is aimed at students. In conducting research, researchers need research subjects to test their hypotheses. This study looks at the implementation of quantitative literacy at the educational level, especially in high school and college.
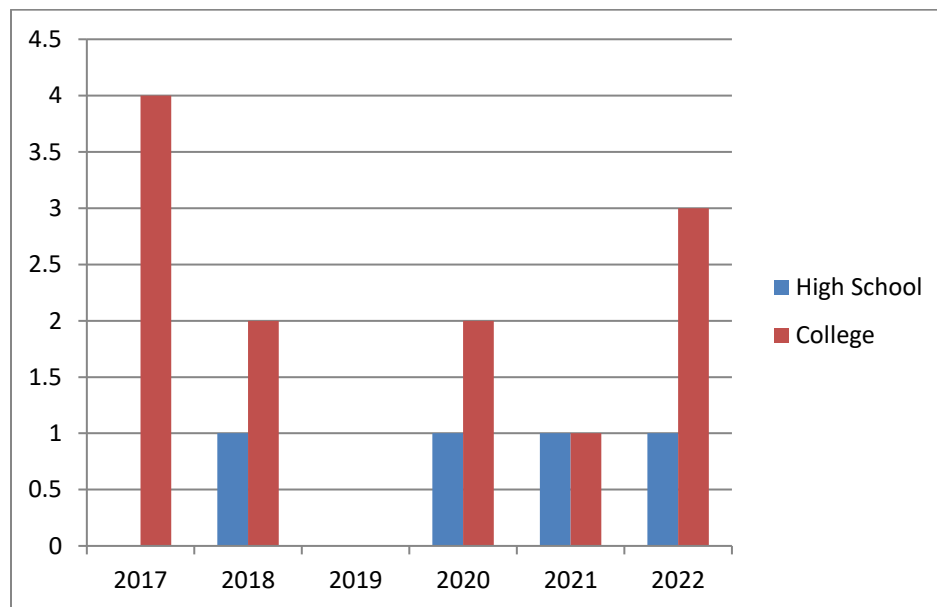
Figure 3. Distribution of number of quantitative literacy research subjects per year based on education level.

Based on Figure 3, the most frequently selected subjects in quantitative research are university-level students. This finding aligns with Flanagan & Einarson's (2017) research that students increasingly face quantitative information. In various biology courses, many students analyze and interpret data in graphs, tables, diagrams, and so on, which contain numbers (Azzahra et al., 2025). Students are asked to use mathematical formulas to represent biological processes, write and solve differential equations describing biological processes, and perform other calculation activities (Olimpo et al., 2018). However, research at the SMA level needs to be conducted to train SMA students with quantitative data. By getting used to dealing with and solving biology problems related to numbers, it is hoped that students' quantitative literacy skills will be honed earlier. When they are in college later, students will get used to and be more comfortable dealing with data in the form of numbers.

Implementation of Learning Models and Media in Efforts to Increase HOTS

Giving treatment aims to test the research hypothesis or identify the significance of certain conditions in each parameter studied. From the research that has been done, several types of research models are used to increase students' HOTS through quantitative literacy. The most widely used model is the inquiry model found in 2 research articles. The inquiry model is known to make students' cognitive structures more structured. The steps in the inquiry learning process are orientation, formulating problems, making hypotheses, collecting data, retesting hypotheses, and making conclusions. The syntax of this model has a significant impact on developing students' critical thinking skills. This study utilized learning media in the form of the EDDIE (Environmental Data-Driven Inquiry and Exploration) project module (Klug et al., 2017) and mind mapping (Senisum et al., 2022).

Another learning model that uses the EDDIE Module is Think-Pair-Share. A study by Soule et al. (2018) revealed that the EDDIE module is a flexible platform for achieving measurable learning outcomes in various pedagogical environments. The EDDIE module is practical in active learning strategies, particularly Think-Pair-Share. It is flexible enough to teach students data analysis skills without access to a computer lab. It is known that positive results in quantitative literacy can be achieved in an active learning environment.

Besides the two previous learning models, several researchers developed and modified existing ones. There are several models applied in research, namely Sosio-Biological Case-Based Learning (Suwono et al., 2017) which presents learning material in the form of cases, and Blended Project-Based Learning (Hujjatusnaini et al., 2022), which proves that the learning model which is integrated with 21st-century skills has a significant effect on HOTS. Another learning model that is proven to increase student HOTS is the ReCODE model (Reading, Connecting, Observing, Discussing, Evaluating) developed by Saenab et al. (2021) and the PBLPOE Model which

integrates Problem-Based Learning (PBL) and Predict, Observe, and Explain (POE) in its application (Fitriani et al., 2020).

From the analysis of the articles carried out, a learning model utilizes ICT, namely the Blended Web Mobile Learning Model developed by Wikanta & Susilo (2022). Research conducted by (Chee et al., 2018) developed the FISCOMOLE learning application, which is not only helpful and easy to use but significantly improves HOTS on biological concepts. With the use of this application, it is known that interaction, collaboration, learning attitudes, and student interest in learning have also increased.

The findings of this study inform that the use of appropriate learning models is proven to help increase students' HOTS. Quantitative literacy-based learning provides opportunities for students to explore data in the form of numbers. Teachers can take advantage of websites that provide material and can be accessed in general, such as the EDDIE module, or by innovating to develop their learning modules and media. The development of this learning media can be integrated with various cases that occur daily in the student's environment and requires the ability to solve problems to practice HOTS through quantitative literacy. Besides that, a quantitative literacy-based learning model integrated with 21st-century skills is also an opportunity for other researchers who want to discuss this matter further. This is because 21st-century skills are one solution to the challenges of the 4.0 revolution era (Wikanta & Susilo, 2022). However, research related to quantitative literacy is used more in subjects with a lot of calculations, such as mathematics, physics, and chemistry.

Selected Biology Topics in Study

Biology is a science that has a wide range of topics. Several topics are manageable, and some are still difficult for students (Fauzi & Fariantika, 2018). Starting from the analysis, several publications are only based on one topic, while others highlight several topics.

Table 2. Percentage of biology topics covered in 16 articles.

Topic	Number of articles	Percentage
Ecology	4	20 %
Genetics	3	15 %
Human Physiology	3	15 %
Cell and Molecular Biology	3	15 %
Biodiversity	1	5 %
Growth and Development	1	5 %
Evolution	1	5 %
Microbiology and Technology	1	5 %
Environmental pollution	1	5 %

Based on Table 2, several topics were selected by the researchers for their research at the high school and university levels. In particular, ecology is the most frequently

chosen topic for conducting research related to quantitative literacy. A total of four publications reviewed the level of students' thinking skills related to ecology. The research of Klug et al. (2017) dan Soule et al. (2018) revealed that this topic was chosen because, through ecological data, students can access, manipulate, analyze, and use this data to pose and answer broad ecological questions. Ecological data has a range of materials that can be quantified in various forms and patterns. The following topics usually raised as the primary concern of quantitative literacy research are genetics, human physiology, and cell and molecular biology. Genetic material was chosen as the context of the discipline because it is closely related to calculations in the process of inheritance (Alsarayreh, 2021; Suwono et al., 2017). Genetic material contains qualitative and quantitative issues that are easier to identify for use as clinical interview assignments (Sung et al., 2022).

In addition to the topics above, the researchers also discussed other topics related to quantitative literacy. Expanding the topics of biology discussed means that research related to quantitative literacy in biology learning is starting to get attention. This refutes the assumption that biology is just rote memorization. Biology also involves data analysis in numbers, graphs, tables, diagrams, etc. From the analysis, several studies did not review the reasons for elaborating the research background about factual conditions between quantitative literacy and the chosen topic. However, the overview of the results of the analysis of the article shows that other researchers have the potential to find solutions to help students become high-level thinkers through quantitative literacy for other biology topics. Biology topics rarely discussed can be studied in more depth in future studies.

HOTS Improvement Potential Through Quantitative Literacy

Quantitative literacy includes the skills to access, manipulate, and analyze quantitative data sets (Klug et al., 2017). Besides that, quantitative literacy requires the ability to use the data to ask and answer various questions and solve various problems in everyday life. In this case, problem-solving skills and critical thinking are needed. Students' higher-order thinking skills also develop by getting used to dealing with quantitative data. In a study by Soule et al. (2018), students explore and analyze data in class and solve more complex problems in homework assignments. From the results of this study, the learning outcomes of students who took part in a learning process based on quantitative literacy increased. Besides that, statistical reasoning, understanding of nature-of-science (NOS), and understanding of concepts have also increased.

Several reports highlight the increasingly quantitative nature of biological research and the need to innovate. The research by Stanhope et al. (2017) has confirmed that students acquire quantitative skills by presenting a tool to support this innovation as a biological science quantitative reasoning test (BioSQuaRE). Assessment instruments

designed to measure students' quantitative skills in the context of biology also have the potential to increase HOTS through quantitative literacy.

CONCLUSION

This study reviewed articles highlighting efforts to increase HOTS through quantitative literacy published in 16 articles. It was found that there was a tendency to increase research variations in various methods to address this issue. Researchers most widely use the quasi-experimental method by applying various learning models. Meanwhile, the biology material most widely used in quantitative literacy research is ecology at both high school and college levels. The results of the research that has been done show that involving students in learning through data in the form of numbers can train their quantitative literacy. They can hone their thinking skills by analyzing, visualizing, and interpreting data in the form of numbers. From the findings of this study, other researchers can further explore efforts to increase HOTS through quantitative literacy using correlational and RnD methods because this research is still limited. More diverse biology topics can be used in subsequent research by utilizing engaging learning media.

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