Enhancing Higher Order Thinking Skills Disposition in a Junior High School Physics Class through Science Writing Heuristic Approach

Shuangshuang Yuan
Department of Life Science,
Changzi University, China
shsd_yss@126.com

Nagalingam Karuppiah
Member,
Education Service Commission of Malaysia
Nagalingam60@yahoo.com

Kam-Fong Lee*
Faculty of Education, Languages, Psychology and Music,
SEGi University, Malaysia
leekamfong@segi.edu.my

Abstract:
This study investigates the effectiveness of integrating the Science Writing Heuristic (SWH) approach into a junior high school physics classroom. The research aims to explore the impact of SWH on high order thinking skills disposition of students and to examine the perspectives on its effectiveness for classroom learning. Two research questions are posed: (1) Does the SWH approach improve high order thinking skills of junior high school students? and (2) What are the students' perspectives on the effectiveness of the Science Writing Heuristic approach for classroom learning? A mixed-methods research design, including a pre-test and post-test control group design and interviews with teachers and students, was used. The SWH approach, grounded in constructivist learning theory, emphasizes the importance of active engagement in the learning process. Potential benefits of SWH include developing higher order thinking skills and increasing student engagement and motivation. However, challenges may arise from the need for teacher training and support, and potential workload and time constraints. The study's findings offer insights for educators interested in innovative teaching approaches in their classrooms. Further research could focus on the impact of SWH on specific higher order thinking skills and its potential benefits for other grade levels and subject areas.

Keywords: Science Writing Heuristic, physics classroom, junior high school, high-order thinking; science inquiry; experiment learning

1 Introduction

With the development of society and the exponential growth of knowledge, the mode of thinking based on simple memorization, understanding and application of knowledge has long failed to meet the needs of society, but requires the cultivation and development of students' higher-order thinking. There is consensus that higher-order thinking is one of the decisive factors in determining students' academic performance and employment performance (Luo Mingdan & Tang Guangquan, 2022; Prayitno et al., 2018). Educators and researchers have underscored the growing importance of higher-order thinking (Baguma et al., 2019). The field of science education is no exception, and there has been a growing emphasis on promoting HOTS in science classrooms. These skills are essential for success in today's rapidly changing and complex development in science education, where students must be able to analyze, evaluate, and synthesize information to solve complex problems. Physics, in particular, is a subject that requires students to engage in higher-order thinking, as it involves complex concepts and abstract ideas that are often difficult to understand. However, traditional approaches to teaching physics often prioritize rote memorization of formulas and concepts, which may not effectively develop students' HOTS. Therefore, strategies to develop junior high school students' higher-order thinking in the teaching-learning process warrants attention.

1.1 Research problem

The Chinese 2022 Edition Science Curriculum Standards for Compulsory Education emphasize the development of higher-order thinking skills, including critical and creative thinking (The Ministry of Education of the People's Republic of China, 2022). Despite this emphasis, promoting higher-order thinking in the context of classroom teaching remains a significant challenge in science education in China. Inquiry-based teaching, which is advocated as the dominant way of learning in the new curriculum standards, has been criticized for focusing too heavily on operational skills training in developing students' thinking abilities (Hu, 2022; Y. Li & Sang, 2020). To address this issue, there is an urgent need to explore effective approaches to optimizing the science inquiry process and improving students' higher-order thinking skills. This study aims to investigate the impact of the Science Writing Heuristic (SWH) approach on junior high school students' higher-order thinking skills in the context of physics education, with a view to providing insights into how inquiry-based teaching can be effectively implemented to promote students' higher-order thinking.

1.2 Research questions

The science writing heuristic (SWH) approach, as a writing tool in science experiment, is well accepted and can promote students to conduct the experimental inquiry, form scientific thinking and acquire scientific knowledge with the help of argumentation structure and the application of scientific language (Bae et al., 2021; Hand et al., 2018; Hand & Chen, 2020). However, there are only a few studies that investigated SWH in China (Cai, 2010; M. Li & Wang, 2020). Underlying this background, this study aims to explore the effectiveness of the SWH approach in promoting the development of higher-order thinking among students in a Chinese junior high school physics classroom. The following two questions are formulated:

1) Is the SWH approach effective in improving junior high school students' higher-order thinking?
2) What are the students’ perspectives on the effectiveness of the SWH approach for use in classroom learning?

2. Research background

In China, influenced by the indoctrination style of education, educators only focus on the results of students' learning outcome, while neglect the process; focus on students’ lower-order thinking and neglect higher-order thinking development (Sun et al., 2022). While, the PISA test results also show that Chinese students perform poorly in complex cognitive skills such as high-order thinking skills (Shang & Qiu, 2018). However, effective learning or teaching models that point to the cultivation of higher-order thinking need to be further researched and refined (Ma & Yang, 2021). Recently, the inquiry-based instructional has been widely promoted in science education, researchers have found that it is associated with lower achievement (Aditomo & Klieme, 2020; Chi et al., 2018) and lower levels of scientific literacy (Oliver et al., 2021). In China, the value and effectiveness of inquiry-based instruction have recently raised concerns. Therefore, the need to find appropriate instructional strategies to help teachers achieve the goal of raising higher order thinking in the inquiry-based learning is highly pressing.

SWH is an approach to teaching and learning writing that is widely used in science to promote experimental inquiry, scientific thinking, and the acquisition of scientific knowledge through the use of argumentation and language (Hand & Chen, 2020; Nikmatuzaroh, 2019). Fatih et al. (2020) emphasized that SWH writing activities provide students with opportunities for deeper thinking through the process of writing compared to traditional instruction. In addition, SWH approach places a high value on the argumentation component of the science inquiry process (Martin & Hand, 2009). Students often encounter many different claims when formulating arguments, and they need to assess them by using reasoning, analysis, and other higher-order thinking in their own minds. At the same time, students often engage in diverse communication with teachers and peers when making arguments, which can be a good opportunity to stimulate their thinking. Therefore, the implementation of the SWH method is very conducive to the development of higher-order thinking as it not only helps them learn to make judgments about theories and information, but also stimulates them to actively express their opinions or raise questions and rebuttals, etc.

This study aims to investigate the effectiveness of SWH (Science Writing Heuristic) intervention in improving students' higher order thinking skills, including problem-solving, critical thinking, science inquiry, and creative thinking. Specifically, SWH writing tasks will be integrated into the physics classroom, and the impact of this intervention will be evaluated after one semester.

2.1 Conceptual framework

Based on the background information presented, a conceptual framework is established to examine the impact of SWH on higher-order thinking skills, as illustrated in Figure 2.1. The independent variable is the SWH approach, while the dependent variable is the level of disposition of higher-order thinking skills exhibited by students.

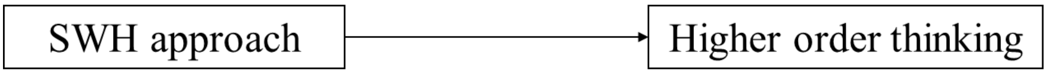

Figure 2.1 Conceptual framework

3. Literature Review

3.1 Constructivism

Constructivist theory emphasizes the student-centered orientation, which means that students should be shifted from passive recipients of external stimuli and objects of knowledge inculcation to subjects of information processing and active constructors of the meaning of knowledge; and teachers should be shifted from transmitters and inculcators of knowledge to helpers and facilitators for the students' active construction of meaning (He, 1997). Constructivism believes that the student's "acquisition" of knowledge can only be accomplished by his own construction. Learning is not only about understanding new knowledge, but also involves analyzing, testing and critical of new knowledge.

Meanwhile, constructivism emphasizes the experience of learners and believes that learners do not walk into the classroom with nothing in minds (Fedyk & Xu, 2018; Suhendi et al., 2021). They have formed rich experiences in their daily lives and previous learning, so instruction cannot ignore these experiences, on the contrary, it should take children's existing knowledge experiences as the growth point of new knowledge and guide children to "grow" new knowledge from their original experiences (M. Kara, 2019; Y. Liu, 2021). Thirdly, since knowledge is actively constructed by individuals, it cannot be directly transmitted to students through teachers' explanations (John, 2018). Therefore, students must actively participate in the entire learning process to construct the meaning of new knowledge based on their prior experiences. Teachers should value learners' own understanding of various phenomena and use it as a basis for guiding students to enrich or adapt their own understanding. In addition to imparting knowledge and answering confusion, teachers should be facilitators and guides who support students in constructing knowledge (Candra & Retnawati, 2020; Hus & Jančič, 2019). Teaching is student-oriented, so that they can learn independently and creatively and become self-educated social subjects.

Constructivism focuses on interactive approaches to learning (Jitka et al., 2018; Titis, 2019). Constructivist theory views knowledge as a social construct that is negotiated and agreed between individuals and others. Therefore, science must be learned through conversation and communication, where different views are presented to stimulate individual reflection and thought. The process will clarify the doubts that arise through interactive questioning and argumentation, and gradually develop formal knowledge. Thus, this study is based on pedagogical constructivism and the constructivism in this study represents pedagogical constructivism.

It is widely accepted that constructivism can facilitate the liberation of children's thinking (Lochhead, 1989). Learning is a process in which children construct knowledge and form thinking gradually through their own active activities, and knowledge develops through a series of forms, or stages of thinking (Carpendale et al., 2020). The constructivist philosophy of education is in line with the current educational situation, where knowledge is vast and one that evolved rapidly, and it is neither possible nor necessary to teach "all knowledge" to students, therefore, teaching and learning activities should focus on the development of children's thinking abilities, especially higher-order thinking (Hu, 2019; Lu et al., 2018).

Constructivist-based instruction can promote students' higher-order thinking development, Tunca (2015) found that constructivist learning environment features were largely effective in supporting students' critical thinking development when analyzing the results of several studies. Therefore, it is reasonable and feasible to choose constructivist theory as the basis for this study to achieve the improvement of higher-order thinking for junior high school students.

3.2 Generative learning theory

Merlin Wittrock first introduced the concept of generative learning in his 1974 article "Learning as a Generative Process" (Osborne & Wittrock, 1985). Wittrock (1988) described the learning process as "a function of the abstract, unique, and concrete connections that learners make between their prior experiences stored in long-term memory and the stimuli" (p. 41). In the view of generative learning theory, knowledge formation is the process of constructing meaning out of new stimuli with the help of the knowledge in the learner's mind, which is considered not only a constructive process but also generative (Fiorella & Mayer, 2016).

The generative learning model is formed by combining the generative learning theory with information processing theory, as portrayed in Figure 3.1. This model attempts to explain how the components of generative learning theory motivate students to think and encourage them to discussion. First, when learners receive external stimuli, they select which information to pay attention to while ignoring others given their prior knowledge. Next, the learners make connections between the noticed information and the ideas already in their mind, and the new combination of external stimuli and these connections is the knowledge that the learner constructs. Finally, the learner can store the constructed meaning in long-term memory or compare and subsume it with other aspects of memory storage or with meaning constructed by other sensors.

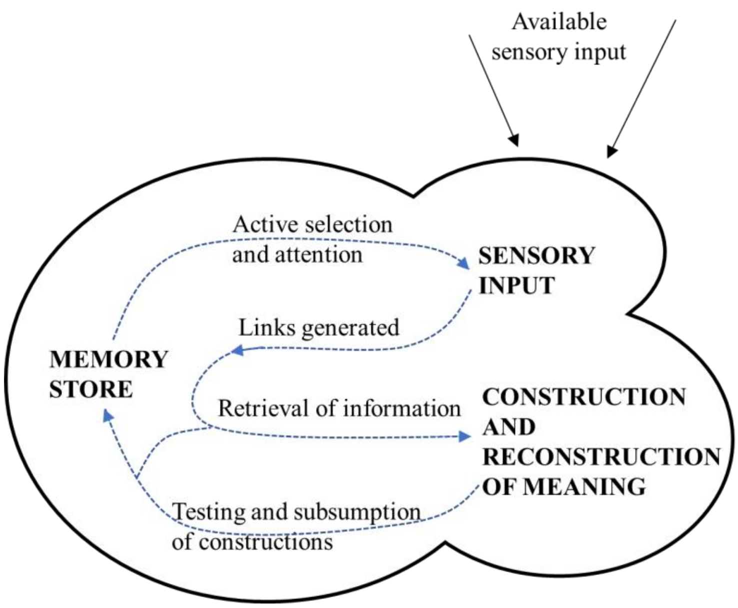

Figure 3.1 Schematic representation of the generative learning model
(Source: Osborne & Wittrock, 1985)

The SWH approach is an example of a generative approach in the realm of science (Hand & Chen, 2020). During immersion in the SWH approach, students encountering new knowledge situations need to go through complex processes to generate new ideas. The dialogic interaction of constructing arguments, writing using all the necessary language and further constructing arguments means that students have to use a range of generative strategies as they engage in a different set of complex processes to develop their knowledge (Hand & Chen, 2020). Students need to negotiate with their prior knowledge, explore phenomena by asking questions, generate claims and evidence in response to these questions, and yield a final summary writing piece in this progress (Hand & Chen, 2020).

3.3 Past literature

3.3.1 Higher-order thinking

Bloom's Taxonomy of Education Objectives is believed to be the origin of higher-order thinking (Alshaiji & Al-saeed, 2021; Huang & Ning, 2021; Oktaviana & Susiaty, 2020). In order to better guide educational practice with Bloom's Taxonomy, Anderson et al., (2001) revised the Bloom's taxonomy, namely remember, understand, apply, analyze, evaluate, and create, which is well-agreed as the definition of higher-order thinking (Alshaiji & Al-saeed, 2021; Sole & Anggraeni, 2020). However, differing from Bloom and Anderson's understanding of higher-order thinking which is based on the complexity of cognition, there have been many scholars in recent years who have defined higher-order thinking based on the intrinsic meaning of thinking. Lewis and Smith (1993) thought that the following goals can be achieved through higher-order thinking: “deciding what to believe; deciding what to do; creating a new idea； a new object, or an artistic expression; making a prediction; and solving a nonroutine problem.”

Higher-order thinking, which essentially important for solving complex problems, involves many aspects such as the ability to think creatively and critically, make decisions and solve problems (Zhong, 2005). Hwang et al. (2020) argued that higher-order thinking covers three components: critical thinking, creative thinking, and problem-solving skills. Given that the aforementioned perspectives demonstrate that the connotation of higher-order thinking is complex and multifaceted, this study provides a thorough definition that combines perspectives on cognitive aims, processes, aspects, and characteristics. Higher-order thinking, which includes critical thinking, creative thinking, science inquiry, and problem-solving abilities, is a high level of mental activity that is capable of solving complex problems in a critical and creative manner.

There is a growing number of studies in recent years related to higher-order thinking, including research on thinking skills, curriculum, instruction, and learning (Liu et al., 2021). Given the undoubted impact of instruction on higher-order thinking, there is a tremendous amount of research focused on how to improve students' higher-order thinking through teaching. Inquiry-based learning is recognized as a good way to develop higher order thinking, while, the 5E inquiry-based learning, the Problem Based Learning (PBL) and blended learning models as well (Hmelo & Ferrari, 1997; Nguyễn, 2021; Prahani et al., 2021; Suhirman et al., 2020). In summary, it was found that most instructional models used to promote higher-order thinking emphasize on the elements of problem, challenging task design, motivating student initiative, group collaboration (cooperation), and concern for communication and sharing. These studies provide directions and ideas on how to improve students' higher-order thinking in the future, notably through teaching in schools.

3.3.2 Inquiry and argument-based inquiry

Inquiry-based teaching and learning are supported by constructivism theory, which emphasizes the development of student’s independent thinking and collaborative skills (Friesen & Scott, 2013; Hu, 2022). In China, inquiry has already been the main mode of teaching science. Since the Ministry of Education of the People's Republic of China promulgated the General High School Science Curriculum Standards in 2013, it has been advocated inquiry-based learning in the basic notion of the curriculum (The Ministry of Education of the People’s Republic of China, 2022). Inquiry-based learning is conducted based on students' curiosity about everything, which not only stimulates children's interest in learning, but also helps students understand scientific concepts, develop learning abilities and generate scientific literacy, which is an essential way of the junior high school science class. However, the effectiveness of inquiry-based instruction is still limited, and quite a number of teachers value the operational elements of inquiry too much, believe that students' "hands-on operation" and "participation in activities" are inquiry (Zhao, 2019), which lead students only interested in the experimental phenomena or the so-called " correct" results. Most of them will not explore or discuss and communicate in depth when they encounter different results, and tend to accept the knowledge from textbooks or their teachers (Yang, 2020).

Furthermore, when engaged in the inquiry, teachers tend to neglect the learning process and students' affective experiences in the learning process, especially the development of students' learning skills, thus resulting in few opportunities for students to express their views and opinions(Yang, 2020). The function and value of science argumentation as a centerpiece of inquiry has been downplayed in inquiry-based learning and teaching (Rapanta & Felton, 2019). Argumentation is considered necessary for the implementation of inquiry-based teaching activities (Jang & Hand, 2017; Mi et al., 2022). As a result, many researchers recommend enhancing students' science argumentation in inquiry-based instruction (Cavagnetto et al., 2010; Rapanta & Felton, 2019; Taufik et al., 2019; Villanueva et al., 2012).

In science inquiry activities, argumentative teaching refers to the process in which teachers and students concentrate on a certain topic, use inquiry activities and other scientific methods to collect evidence, then apply certain argumentation methods to judge, explain and evaluate the ideas between themselves and others', so as to reach a generally acceptable conclusion. Some researchers argue that students will not fully understand the nature of science if they are not given the opportunity to argue, construct explanations, and evaluate evidence during the inquiry process (Hartini et al., 2020; Hwang et al., 2020). To fully and correctly understand science concepts, they need to go through an argumentative process that involves mutual communication and argumentation with peers, in which their flow of thinking is fully exposed. Argumentation promotes a sophistication of thinking as learners openly use evidence to support their claims through written or spoken language while evaluating and refuting ideas and interpretations that are opposed to their claims (K. Chen & Ma, 2018).

In addition, the integration of scientists' argumentation into the inquiry allows students to better appreciate the scientist-like thinking and methods mode, therefore, argumentation-based teaching is an effective way to cultivate and develop students' higher-order thinking (Daningsih et al., 2019). Argumentation is the core component of inquiry, and inquiry-based teaching is currently the main teaching and learning mode in science teaching, so it is pressing to identify an instruction mode that can embody the argumentation in science education. Considerable studies have been conducted focusing on scientific argumentation teaching approaches, and various teaching models have been proposed (Akkus et al., 2007; Rapanta & Felton, 2019), among them the ADI (Argument-Driven Inquiry) model and the SWH approach have received considerable attention and yielded a series of related studies.

3.3.3 The science writing heuristic approach

The SWH model is an argument-based inquiry designed and addresses students' constructing scientific knowledge as they engage in inquiry activities (Shin & Choi, 2020). Keys and Hand suggested that students should be given more opportunities to focus on ideas rather than on the operation of the experimental apparatus and the completion of the experiment (Keys, 1999).

Therefore, they developed the Science Writing Heuristic (SWH) approach to guide students when they are writing lab reports，SWH is used as a tool to facilitate students' experimental inquiry, scientific thinking, and scientific knowledge acquisition through the use of argumentative structure and scientific language (Hand et al., 2004).

The tool includes a teacher template and a student template (Baaijen & Galbraith, 2018; Keys et al., 1999), as shown in Table 1, it connects traditional lab reports to personally constructed writing, linking scientific content to language activities through the process of "questions, methods, observations, opinions, evidence, judgments, and transformations", stimulating students to engage in argumentation, thus promoting the connection between ideas, data, and evidence of the experiment. The teachers' template provides a series of suggestions for activities that are designed to help teachers design instructional activities and organize students to engage in meaningful thinking, writing, reading, and discussion while doing the experiment, as illustrated in table (Hand et al., 2016; Keys et al., 1999). The students' template provides a semi-structured writing framework aimed at guiding students to engage in experimental activities and activities such as negotiation and writing (Hand et al., 2016; Keys et al., 1999).

Table 1 The teacher template and the student template
(Source: Hand et al., 2015)

The science writing heuristic, Part I A template for teacher-designed activities to promote laboratory understanding	The science writing heuristic, Part II A template for students
1. Exploration of pre-instruction understanding through individual or group concept mapping	1. Beginning ideas—What are my questions?
2. Pre-laboratory activities, including informal writing, making observations, brainstorming, and posing questions	2. Tests—What did I do?
3. Participation in laboratory activity	3. Observations—What did I see?
4. Negotiation phase I—writing personal meanings for laboratory activity (for example, writing journals)	4. Claims—What can I claim?
5. Negotiation phase II—sharing and comparing data interpretations in small groups (for example, making group charts)	5. Evidence—How do I know? Why am I making these claims?
6. Negotiation phase III—comparing science ideas to textbooks for other printed resources. (for example, writing group notes in response to focus questions)	6. Reading—How do my ideas compare with other ideas?
7. Negotiation phase IV—individual reflection and writing. (for example, creating a presentation such as a poster or report for a larger audience.)	7. Reflection—How have my ideas changed?
8. Exploration of post-instruction understanding through concept mapping.	

The first seven steps of the teacher template are presented in correspondence to the student template, and the teacher's role is to guide the students' participation in activities. In the first step, the teacher evokes students' prior knowledge and in doing so the student generates initial ideas about the problem.

In step two the teacher organizes students' discussion and informal writing to clarify the issues related to the topic. In step three, the teachers' schedules experimental activities and students are expected to write down their observations. The main content of SWH is covered in steps 4-7, where the teacher prepares a series of negotiation activities and writing opportunities to guide students in thinking about their ideas, statistics, and evidence. Step eight is the teachers' reflection of the whole instruction (Hand & Chen, 2020).

Countless studies have shown that applying SWH in science classrooms can promote students' understanding of scientific concepts (K. Chen & Ma, 2018), foster students' higher-order thinking, such as critical thinking and problem-solving skills (Ankrah, 2012; Fatih et al., 2020), enhance students' writing abilities (Y. C. Chen et al., 2016; M. Li & Ding, 2018), improve argument ability (Taufik et al., 2019), and boost their academic achievement and scientific literacy (Nikmatuzaroh, 2019; Shin & Choi, 2020). Bae et al. (2021) conducted a meta-analysis of ten quantitative SWH empirical studies that were undertaken in Turkey and found that students performed significantly better in academic achievement tests in SWH-based classrooms than in conventional ones (Bae et al., 2021), and the SWH was the most popular approach among all kinds of science writing paradigms (K. Chen & Ma, 2018). Hand and Chen, one of the proponents of the SWH, made a systematic review in 2020 highlighting 81 doctoral and master's theses which employed the SWH approach in their researches, found that students showed significant advantages in terms of knowledge, critical thinking, and representational skills, regardless of their grade level and cultural background (Hand & Chen, 2020).

Finally, in terms of the research subjects, most of the studies focused on high school and above, and only a few focused on junior high school (Bae et al., 2021; Hand & Chen, 2020). But there also some studies that show the promising possibility of applying SWH in junior high school. For example, S. Kara and Kingir (2022) conducted a quasi-experimental study with 107 students in four fourth grade classes in a Turkey public junior high school. The results showed that students in the treatment group developed significantly in their ability to use models to construct arguments, besides, the conceptual understanding of students in the treatment group also improved. One study conducted in the Midwest USA indicate that instruction embedded with the SWH approach can contribute to improved student performance in science and language, especially for disadvantaged students (Hand et al., 2016).

Writing has traditionally been integrated into Mandarin and English curricula in China, but science writing has not received much attention in classrooms (M. Li & Wang, 2020). Additionally, there is a lack of research on implementing science writing specifically in junior high school settings. To address this gap, this study aims to introduce the SWH approach in junior high school science classrooms to enhance science writing experiences and provide insights for secondary science education.

3.3.4 Related studies on the relationship between SWH and higher order thinking

Numerous empirical studies have found that SWH can effectively promote students' higher-order thinking development. For example, findings from previous SWH studies suggest that learning to write during science activities can develop students' conceptual understanding and logical reasoning (Keys, 1999). In addition, Fatih et al., (2020) found that writing learning activities had a significant impact on prospective teachers' critical thinking skills and critical thinking dispositions by guiding them to do research, argue, communicate, and reflect, and suggested using writing learning activities to develop higher-order thinking, following a writing instruction intervention with prospective teachers. Arslan (2022) found through a comprehensive and critical study of 73 graduate theses in the field of science education that writing can improve students' creative writing. However, different conclusions have also been reached, and Uzoğlu (2014) states that writing learning activities are ineffective in developing higher-order thinking such as critical thinking. Meanwhile, few research were conducted in China.

3.4 Theoretical Framework

The theoretical framework of this study is mainly based on two theories and a taxonomy, namely, Constructivism, generative learning theory and Bloom's taxonomy.

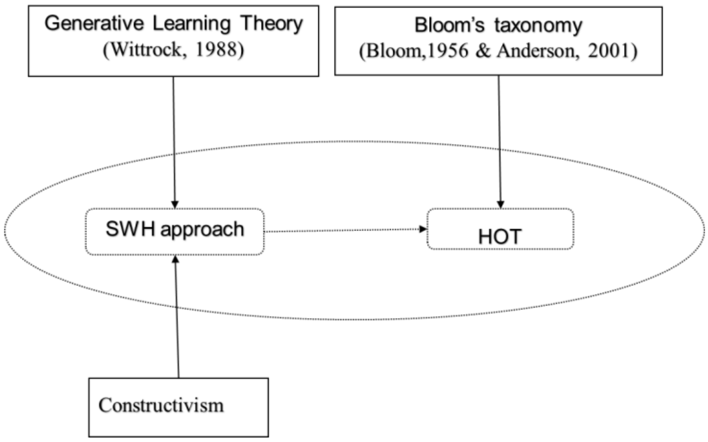

Figure 2.4 Theoretical framework of the present study

The study is grounded in the theoretical framework of constructivism, which provided the foundation for the research design and analysis. An understanding of constructivist principles is essential in developing an inquiry-based approach using SWH and allowed for a thorough examination of the research phenomenon and the drawing of reliable conclusions. The adoption of a constructivist perspective also facilitated the interpretation and analysis of the study's findings.

Bloom's taxonomy is a widely used model that categorizes thinking skills into six levels ranging from lower-order thinking to higher-order thinking (Bloom et al., 1956). A thorough understanding and analysis of this taxonomy can provide researchers with a valuable tool for assessing and evaluating students' higher-order thinking skills. By examining the different levels and variations of higher-order thinking, researchers can gain insight into students' abilities to apply, analyze, synthesize, and evaluate information, which are essential skills in today's complex world (Krathwohl, 2002).

The generative learning theory forms the core theoretical foundation of the SWH approach (Hand & Chen, 2020). By utilizing this theory in the research process, researchers and practitioners can gain a deeper understanding of the cognitive development process of learners (Rieu et al., 2022). Additionally, the use of generative learning theory can aid researchers in elucidating how the various components of the theory stimulate students to think critically and construct coherent arguments. This, in turn, can facilitate a more rigorous analysis of the collected data, leading to scientifically sound conclusions.

4. Administration of SWH approach intervention

The entire teaching intervention will be conducted from April 1st to July 1st, 2023, covering a total of 12 weeks over the course of one semester. The instructional time for each unit will be scheduled equally for both groups. The instructional schedule for both groups include one 40-min periods per week for 10 weeks. At the beginning of the intervention, two activities will be organized to help teachers and students understand the SWH methodology during the first two weeks, namely the teacher training phase and the introductory phase as shown in Table 2. First of all, a training on the SWH method will be held by the researcher in order to enable the cooperating teachers to use the SWH method more effectively. Then, an introduction of the SWH approach will be delivered to the students in the experimental group to better implementations. The last 10 weeks of the semester will be the formal implementation of the SWH approach.

Table 2. The schedule of the intervention in the experimental group

Date	Plan	Participants
Week 1 -Week 2	ing of Cooperating Teacher	searcher; 'o cooperating Physics teachers.
Week 3 - Week 4	duction of the SWH approach.	searcher; 'o cooperating Physics teachers; idents.
Week 5 - Week 14	al implementation of the SWH oach interventions.	searcher; 'o cooperating Physics teachers; idents.

4.1 Instruction in the experimental group

The teacher will carry out the activities according to the SWH approach, prepare the lesson plans and revised them based on the researcher's feedback. Students will be divided into two students one group by the cooperating teacher, who is familiar with them, ensuring heterogeneity with respect to gender, prior achievement, communication skills, and personality traits; they remain in the same group throughout the implementation period. The researcher will interact with the teachers throughout the implementation process—reviewing the content of the lesson before the class and giving feedback after instruction. When implementing the lesson plans, the students will be assigned with a pre-course preparation task to elicit students' prior knowledge and help them think about the questions they want to investigate in class. In each class session, students will determine the explore questions and finish the whole writing sheets in groups.

4.2 Instruction in the control group

The teachers will employ traditional instruction to teach, which mainly using a strategy of lecturing and questioning. They began by asking the students whether they did the homework assigned the previous week. The teachers will use projection devices to enhance their lectures with videos and presentations through the education portal as well as relying on textbooks.

4.3 Data collection and data analysis

The following section explains the procedures taken to collect and analyse data of the present study. For the research question 1, students' higher-order thinking skills dispositions, which is adapted from Ding (2022) and is primarily used to assess students' physics higher-order thinking skills dispositions will be deployed to collect data from students. The Cronbach's alpha coefficients for the three factors are 0.958, 0.977, 0.968, and 0.843 respectively, and the total alpha coefficient is 0.980. The questionnaire will be delivered to students both in the experimental group and control group at the very beginning and at the end of the intervention. The data will be analyzed by SPSS 25.0 to determine whether there is distinct difference between the two groups in higher-order thinking.

As for the research question two, at the last week of the semester, semi-structured interviews will be conducted with six students in the experimental group, using purposeful stratified sampling. The students will be divided into three groups according to their writing scores: high, medium, and low, and two to three students will be randomly selected for interview. The time for each student's interview is approximately 45 minutes. The interviews will be recorded throughout with the consent of the interviewees. After the interviews finished, they will be converted to text by two researchers to facilitate further thematic analysis to explore the students' perspectives on the effectiveness of the Science Writing Heuristic approach for classroom learning.

5. Discussion

The theoretical framework of the Science Writing Heuristic (SWH) approach is grounded in constructivist learning theory. This theory emphasizes the importance of active engagement in the learning process, where students construct their own knowledge through inquiry-based activities (National Research Council (NRC), 1996). According to SWH, students learn best when they are engaged in scientific inquiry and are actively constructing their own knowledge (Erkol et al., 2010; Keys et al., 1999). This aligns with the goals of physics education, which seeks to promote critical thinking, problem-solving, and scientific literacy (The Ministry of Education of the People's Republic of China, 2022). SWH approach is built on the premise that writing is an integral part of scientific inquiry, and therefore, should be used to promote scientific literacy (Keys et al., 1999). The approach encourages students to use writing as a tool to reflect on their scientific observations, analyze data, and construct explanations (Hand & Chen, 2020). By engaging in writing activities, students can develop their scientific communication skills and improve their ability to articulate their scientific ideas effectively. The Science Writing Heuristic (SWH) approach is a promising instructional framework for improving physics education in junior high school. The approach aligns with constructivist learning theory and the goals of physics education, promoting critical thinking, problem-solving, and scientific literacy. By integrating writing activities into scientific inquiry, the SWH approach can help students develop their scientific communication skills, improve their ability to articulate their scientific ideas effectively, and enhance their understanding of scientific concepts.

Integrating the SWH approach into the physics classroom could yield several benefits. One of the primary benefits is that it can enhance the development of higher-order thinking skills, such as analyzing and evaluating scientific evidence and constructing coherent arguments (Keys et al., 1999). Research suggests that the SWH approach can be effective in improving students' higher-order thinking skills (Hand & Chen, 2020; Keys et al., 1999), which suggests that it has the potential to be a valuable tool for promoting student learning in the physics classroom. The SWH approach also provides opportunities for active, hands-on learning, which can increase student engagement and motivation (Keys et al., 1999). The potential benefits of implementing the SWH approach in the physics classroom make it an approach worth considering for educators seeking to enhance their students' scientific literacy and critical thinking skills.

However, it is important to acknowledge that implementing the SWH approach in the classroom can pose potential challenges. These challenges include the need for teacher training and support to effectively implement the approach, as well as the potential for increased workload and time constraints for both teachers and students (Hand & Chen, 2020; Keys et al., 1999). Incorporating the Science Writing Heuristic (SWH) approach into the physics classroom requires a significant investment of resources and support. Teachers will need comprehensive training on how to effectively implement the approach and access to appropriate lab equipment and materials. For example, they may require training on how to effectively integrate SWH with existing lesson plans or assignments and how to provide feedback on students' writing.

Furthermore, implementing SWH may require modifications to the existing curriculum, which could present challenges for teachers. For instance, teachers may need to adjust their lesson plans to incorporate SWH, which could impact the amount of time available for other activities. In addition, stakeholders' perspectives on the effectiveness of SWH in the physics classroom may vary. Teachers may have concerns about the workload and time constraints associated with implementing the approach, while students may have varying levels of engagement and motivation. Therefore, it is important to provide adequate support to both teachers and students to ensure successful implementation of SWH. Despite the potential challenges, the benefits of SWH for student learning and engagement make this investment worthwhile.

6. Conclusion

In conclusion, the Science Writing Heuristic (SWH) approach has the potential to enhance high order thinking skills in junior high school physics students. The approach emphasizes active engagement in scientific inquiry and promotes the construction of knowledge through hands-on learning experiences. The integration of SWH into the classroom can help students develop critical thinking skills, construct coherent arguments, and analyze scientific evidence. However, the successful implementation of the SWH approach requires careful planning, preparation, and teacher training. The challenges associated with integrating SWH should not be overlooked, but with proper support and resources, the benefits of this approach can outweigh the challenges.

7. Proposed frameworks for future study

Further research is needed to fully understand the impact of the SWH approach on student learning and engagement in the physics classroom. One potential avenue for future research could be to examine the specific impact of SWH on higher-order thinking skills, such as argumentation and evaluation of evidence. This would provide a more in-depth understanding of the approach's effectiveness and could potentially inform further development of the SWH approach. Additionally, research that explores the potential impact of SWH on other subject areas or grade levels could help to expand its use and effectiveness beyond the physics classroom. Such research could offer valuable insights into how the approach can be adapted to meet the needs of students across a range of disciplines and age groups. Overall, further research on the SWH approach has the potential to enhance the understanding of effective teaching practices and contribute to the development of more effective educational strategies.

References

Aditomo, A., & Klieme, E. (2020). Forms of Inquiry-Based Science Instruction and Their Relations With Learning Outcomes: Evidence from High and Low-Performing Education Systems. *International Journal of Science Education, 42*(4), 504–525.

https://doi.org/10.1080/09500693.2020.1716093

Akkus, R., Gunel, M., & Hand, B. (2007). Comparing an Inquiry-based approach known as the Science Writing Heuristic to traditional science teaching practices: Are there differences? *International Journal of Science Education*, *29*(14), 1745–1765. https://doi.org/10.1080/09500690601075629

Alshaiji, H. K., & Al-saeed, S. J. (2021). Effect of Instructions in Course Book Tasks on Promoting Higher-Order Thinking Skills. *English Language Teaching*, *14*(12), 218–226. https://doi.org/10.5539/elt.v14n12p218

Ankrah, E. A. N.-A. (2012). Guided-inquiry Based Laboratory Instruction: Investigation of Critical Thinking Skills, Problem Solving skills, and Implementing Student Roles in Chemistry. In *Voices of Ghana*. https://doi.org/10.2307/j.ctvbtzpxc.54

Arslan, K. (2022). *A Synthesis Study of National and International Graduate Theses on Writing for Learning in Science Education*. *April*. https://doi.org/10.15390/EB.2022.10943

Baaijen, V. M., & Galbraith, D. (2018). Discovery Through Writing: Relationships with Writing Processes and Text Quality. *Cognition and Instruction*, *36*(3), 199–223. https://doi.org/10.1080/07370008.2018.1456431

Bae, Y., Sahin, E., & Student, G. (2021). A Meta-Analytic Review of the Effectiveness of the Science Writing Heuristic Approach on Academic Achievement in Turkey. *Research in Mathematical Education*, *24*(3), 175–199.

Baguma, R., Bagarukayo, E., Namubiru, P., Brown, C., & Mayisela, T. (2019). Using WhatsApp in Teaching to Develop Higher Order Thinking Skills-a Literature Review Using the Activity Theory Lens. In *International Journal of Education and Development using Information and Communication Technology (IJEDICT)* (Vol. 15).

Bloom, B. S., Engelhart, M. D., Furst, E. J., Hill, W. H., & Krathwohl, D. R. (1956). Taxonomy of educational objetives: the classification of educational goals: handbook I: cognitive domain (No. 373.19 C734t). New York, US: D. Mckay.

Cai, T. (2010). Scientific Writing in Science Education. *Global Education*, *39*(4), 85–89.

Candra, & Retnawati, H. (2020). A meta-analysis of constructivism learning implementation towards the learning outcomes on civic education lesson. *International Journal of Instruction*, *13*(2), 835–846. https://doi.org/10.29333/iji.2020.13256a

Carpendale, J. I. M., Lewis, C., & Müller, U. (2020). Piaget's Theory. In *The Encyclopedia of Child and Adolescent Development* (pp. 1–11). https://doi.org/10.1002/9781119171492.wecad100

Cavagnetto, A. R., Hand, B., & Norton-Meier, L. (2010). Negotiating the Inquiry Question: A Comparison of Whole Class and Small Group Strategies in Grade Five Science Classrooms. *Research in Science Education*, *41*(2), 193–209. https://doi.org/10.1007/s11165-009-9152-y

Chen, K., & Ma, H. (2018). A Review of Research on Science Writing Teaching. *HIGHER EDUCATION OF SCIENCES*, *1*, 14–25.

Chen, Y. C., Hand, B., & Park, S. (2016). Examining Elementary Students' Development of Oral and Written Argumentation Practices Through Argument-Based Inquiry. *Science and*

Education, *25*(3–4), 277–320. https://doi.org/10.1007/s11191-016-9811-0

Chi, S., Liu, X., Wang, Z., & Won Han, S. (2018). Moderation of the effects of scientific inquiry activities on low SES students' PISA 2015 science achievement by school teacher support and disciplinary climate in science classroom across gender. *International Journal of Science Education*, *40*(11), 1284–1304. https://doi.org/10.1080/09500693.2018.1476742

Daningsih, A., Purwianingsih, W., & Yuliani, G. (2019). Does science writing heuristic increase secondary school students' argumentation skills? *Journal of Physics: Conference Series*, *1318*(1), 1–6. https://doi.org/10.1088/1742-6596/1318/1/012072

Erkol, M., Kişoğlu, M., & Büyükkasap, E. (2010). The effect of implementation of science writing heuristic on students' achievement and attitudes toward laboratory in introductory physics laboratory. *Procedia - Social and Behavioral Sciences*, *2*(2), 2310–2314. https://doi.org/10.1016/j.sbspro.2010.03.327

Fatih, K., Meral, E., Şimşek, U., & Şahin, I. F. (2020). A Search for a Method to Improve Critical Thinking Skills in Social Studies Teaching: Writing-to-learn. *Review of International Geographical Education Online*, *10*(3), 400–430. https://doi.org/10.33403/rigeo.719222

Fedyk, M., & Xu, F. (2018). The Epistemology of Rational Constructivism. *Review of Philosophy and Psychology*, *9*(2), 343–362. https://doi.org/10.1007/s13164-017-0372-1

Fiorella, L., & Mayer, R. E. (2016). Eight Ways to Promote Generative Learning. *Educational Psychology Review*, *28*(4), 717–741. https://doi.org/10.1007/s10648-015-9348-9

Friesen, S., & Scott, D. (2013). Inquiry-Based Learning: A Review of the Research Literature. *Alberta Ministry of Education*, 1–32.

Hand, B., & Chen, Y. (2020). *Does a Knowledge Generation Approach to Learning Benefit Students ? A Systematic Review of Research on the Science Writing Heuristic Approach*.

Hand, B., Norton-Meier, L. A., Gunel, M., & Akkus, R. (2016). Aligning Teaching to Learning: A 3-Year Study Examining the Embedding of Language and Argumentation into Elementary Science Classrooms. *International Journal of Science and Mathematics Education*, *14*(5), 847–863. https://doi.org/10.1007/s10763-015-9622-9

Hand, B., Wallace, C. W., & Yang, E. M. (2004). Using a Science Writing Heuristic to enhance learning outcomes from laboratory activities in seventh-grade science: Quantitative and qualitative aspects. *International Journal of Science Education*, *26*(2), 131–149. https://doi.org/10.1080/0950069032000070252

Hartini, T. I., Liliasari, S., Agus, S., & Ramalis, T. R. (2020). Concept Mastery of Physical Education Students in Multiple Representation (MR) Based Three Dimensional Solid Object Motion Mechanics (3DSOM). *Journal of Physics: Conference Series*, *1521*(2). https://doi.org/10.1088/1742-6596/1521/2/022015

He, K. (1997). Constructivist Pedagogical Models, Teaching Methods and Instructional Design. *Journal of Beijing Normal University*, *5*, 74–81.

Hmelo, C. E., & Ferrari, M. (1997). The problem-based learning tutorial: Cultivating higher order thinking skills. *Journal for the Education of the Gifted*, *20*(4), 401–422.

https://doi.org/10.1177/016235329702000405

Hu, W. (2019). The Construction of a Curriculum System for the Integration of Creativity and STEM under the Leadership of the Thinking-based Teaching Theory. *The Chinese Journal of ICT in Education*, *2*, 27–30.

Hu, W. (2022). Cultivate Scientific Literacy in Inquiry Practice. *Basic Education Curriculum*, *10*, 39–45.

Huang, Y., & Ning, C. F. (2021). Enhancing critical thinking in Chinese students in physical education through collaborative learning and visualization. *Thinking Skills and Creativity*, *42*. https://doi.org/10.1016/j.tsc.2021.100958

Hus, V., & Jančič, P. (2019). Representation of teaching strategies based on constructivism in social studies. *International Journal of Innovation and Learning*, *25*(1), 64–77. https://doi.org/10.1504/ijil.2019.10016647

Hwang, G. J., Zou, D., & Lin, J. (2020). Effects of a multi-level concept mapping-based question-posing approach on students' ubiquitous learning performance and perceptions. *Computers and Education*, *149*. https://doi.org/10.1016/j.compedu.2020.103815

Jang, J. yoon, & Hand, B. (2017). Examining the Value of a Scaffolded Critique Framework to Promote Argumentative and Explanatory Writings Within an Argument-Based Inquiry Approach. *Research in Science Education*, *47*(6), 1213–1231. https://doi.org/10.1007/s11165-016-9542-x

Jitka, N., Jitka, P., & Pavlína, K. (2018). Teacher ' s Concept of Constructivism in Real Conditions of School. *Journal of Education and Training Studies*, *6*(11a), 133–138. https://doi.org/10.11114/jets.v6i11a.3810

John, P. (2018). Constructivism: Its Implications for Language Teaching and Second-Language Acquisition. *Papers in Education and Development*, 33–42.

Kara, M. (2019). A Systematic Literature Review: Constructivism in Multidisciplinary Learning Environments. *International Journal of Academic Research in Education*, *4*(1–2), 19–26. https://doi.org/10.17985/ijare.520666

Kara, S., & Kingir, S. (2022). Implementation of the Model-Based Science Writing Heuristic Approach in Elementary School Science. *International Journal of Science and Mathematics Education*, *20*(4), 683–703. https://doi.org/10.1007/s10763-021-10191-0

Keys, C. W. (1999). Revitalizing instruction in scientific genres: Connecting knowledge production with writing to learn in science. *Science Education*, *83*(2), 115–130. https://doi.org/10.1002/(sici)1098-237x(199903)83:2<115::aid-sce2>3.3.co;2-h

Keys, C. W., Hand, B., Prain, V., & Collins, S. (1999). Using the Science Writing Heuristic as a Tool for Learning from Laboratory Investigations in Secondary Science. *Journal of Research in Science Teaching*, *36*(10), 1065–1084. https://doi.org/10.1002/(SICI)1098-2736(199912)36:10<1065::AID-TEA2>3.0.CO;2-I

Krathwohl, D. R. (2002). A revision of Bloom's taxonomy: An overview. Theory into practice, 41(4), 212-218.

Lewis, A., & Smith, D. (1993). Defining Higher Order Thinking. *Theory Into Practice*, *32*(3), 131–137. https://doi.org/10.1080/00405849309543588

Li, M., & Ding, W. (2018). Experiment Teaching Design of Alkaline Zinc-Manganes Battery Based on Science Writing Heuristic Strategy. *Chemistry Teaching*, *39*(23), 58.

Li, M., & Wang, Z. (2020). Development and Application of Science Writing Heuristic Tools in Scientific Experiment Teaching. *Chinese Journal of Chemical Education*, *41*(23), 81–86.

Li, Y., & Sang, C. (2020). Reflections and suggestions on the current situation of science teaching in elementary school. *Modern Education Science*, *S1*, 119–120.

Liu, J., Ma, Y., Sun, X., Zhu, Z., & Xu, Y. (2021). A Systematic Review of Higher-Order Thinking by Visualizing its Structure Through HistCite and CiteSpace Software. *Asia-Pacific Education Researcher*. https://doi.org/10.1007/s40299-021-00614-5

Liu, Y. (2021). Making the "Savage Mind": Critical Thinking within Constructivist Epistemology. *Pekinevig University Education Review*, *19*(4), 2–28.

Lochhead, J. (1989). *Liberation Thinking* (Issue 4).

Lu, Z., Liu, D., Chang, L., & Fan, L. (2018). Teaching in The Classroom: Focus on The Development of Students' Thinking. *Elementary Education Curriculum*, *4*, 20–26.

Luo Mingdan, & Tang Guangquan. (2022). The Malaysian Experience and Implications of Higher Order Thinking Education in Primary Schools. *Journal of Teaching and Management*, *08*, 72–76. www.jxygl.com.cn

Ma, S., & Yang, X. (2021). Promoting Higher-Order Thinking through Collaborative Reasoning. *Research in Educational Development*, *41*(24), 64–73.

Martin, A. M., & Hand, B. (2009). Factors affecting the implementation of argument in the elementary science classroom. A longitudinal case study. *Research in Science Education*, *39*(1), 17–38. https://doi.org/10.1007/s11165-007-9072-7

Mi, L., Zhu, Z., Hu, W., Gao, L., Guo, Y., Yang, Q., & Li, X. (2022). The Core Essence of Scientific Argumentation Based on SWH Approach and Examples. *Scientific Forum on Education*, *22*, 33–36.

National Research Council (NRC). (1996). National science education standards. In *National Academy Press*.

Nguyễn, T. T. M. (2021). Using Problem-based Tasks to Promote Higher-order Thinking Skills for TESOL MA Students in Vietnam. *The Interdisciplinary Journal of Problem-Based Learning Using*, *15*(1).

Nikmatuzaroh, R. . dan N. M. (2019). Implementing the Science Writing Heuristic laboratory report format in the undergraduate organic chemistry laboratory. In *Skripsi*.

Oktaviana, D., & Susiaty, U. D. (2020). Development of Test Instruments Based on Revision of Bloom's Taxonomy to Measure the Students' Higher Order Thinking Skills. *JIPM (Jurnal Ilmiah Pendidikan Matematika)*, *9*(1), 21. https://doi.org/10.25273/jipm.v9i1.5638

Oliver, M., McConney, A., & Woods-McConney, A. (2021). The Efficacy of Inquiry-Based Instruction in Science: a Comparative Analysis of Six Countries Using PISA 2015. *Research* *in Science Education*, *51*, 595–616. https://doi.org/10.1007/s11165-019-09901-0

Osborne, R., & Wittrock, M. (1985). The generative learning model and its implications for science education. In *Studies in Science Education* (Vol. 12, Issue 1). https://doi.org/10.1080/03057268508559923

Prahani, B. K., Deta, U. A., Lestari, N. A., Yantidewi, M., Rjauhariyah, M. N., Kelelufna, V. P., Siswanto, J., Misbah, M., Mahtari, S., & Suyidno, S. (2021). A profile of physics multiple representation ability of senior high school students on heat material. *Journal of Physics: Conference Series*, *1760*(1). https://doi.org/10.1088/1742-6596/1760/1/012020

Prayitno, Adi, B., & Titikusumawati, E. (2018). Ehancing Students' Higher Order Thinking Skills in Science Through Instrad Strategy. *Journal of Baltic Science Education*, *17*(6), 1046–1055.

Rapanta, C., & Felton, M. (2019). Mixed methods research in inquiry-based instruction: an integrative review. *International Journal of Research and Method in Education*, *42*(3), 288–304. https://doi.org/10.1080/1743727X.2019.1598356

Shang, X., & Qiu, X. (2018). Educational Assessment Reform: An Investigation of the Feasibility of Higher-Order Thinking Skills Assessment in Paper-Pencil Tests. *Theory and Practice of Education*, *38*(32), 20–22. https://doi.org/10.5860/choice.45-5122

Shin, E., & Choi, W. (2020). Middle School Science Gifted Students' Perceptions of the Effectiveness of Science Classes Using Science Writing Heuristic. *Journal of the Korean Chemical Society*, *64*(5), 277–290. https://doi.org/10.5012/jkcs.2020.64.5.277

Sole, F. B., & Anggraeni, D. M. (2020). Analysis of High Order Thinking Skill (HOTS) in joint midterm examination at YAPNUSDA Elementary School. *Journal of Physics: Conference Series*, *1440*(1). https://doi.org/10.1088/1742-6596/1440/1/012102

Suhendi, A., Purwarno, P., & Chairani, S. (2021). Constructivism-Based Teaching and Learning in Indonesian Education. *KnE Social Sciences*, *2021*, 76–89. https://doi.org/10.18502/kss.v5i4.8668

Suhirman, Y., Muliadi, A., & Prayogi, S. (2020). The effect of problem-based learning with character emphasis toward students' higher-order thinking skills and characters. *International Journal of Emerging Technologies in Learning*, *15*(6), 183–191. https://doi.org/10.3991/IJET.V15I06.12061

Sun, H., Xie, Y., & Lavonen, J. (2022). Exploring the structure of students' scientific higher order thinking in science education. *Thinking Skills and Creativity*, *43*(August 2021). https://doi.org/10.1016/j.tsc.2022.100999

Taufik, A. N., Rahman, T., & Solihin, H. (2019). The Use of Argument Based Science Inquiry Learning Model by Using Science Writing Heuristic Approach to Build Students Argument Ability in Environmental Pollution Theme. *Journal of Physics: Conference Series*, *1157*(2), 1–6. https://doi.org/10.1088/1742-6596/1157/2/022048

The Ministry of Education of the People's Republic of China. (2022). *Science Curriculum Standards for Compulsory Education (2022 Edition)*.

Titis, S. (2019). Bottom-up and Top-dowm Listening processes whithin Cognitive Constructivist

Learning Theory. *Prominent Journal*, *2*(1), 1–19.

Tunca, N. (2015). The Regression Level of Constructivist Learning Environment Characteristics on Classroom Environment Characteristics Supporting Critical Thinking. *Eurasian Journal of Educational Research*, *60*, 181–200. https://doi.org/10.14689/ejer.2015.60.11

Villanueva, M. G., Taylor, J., Therrien, W., & Hand, B. (2012). Science education for students with special needs. *Studies in Science Education*, *48*(2), 187–215. https://doi.org/10.1080/14703297.2012.737117

Wittrock, M. C. (1988). A Constructive Review of Research on Learning Strategies. In *Learning and Study Strategies*. ACADEMIC PRESS, INC. https://doi.org/10.1016/b978-0-12-742460-6.50022-0

Yang, W. (2020). *Research on the Application Strategy of Inquiry Learning inPrimary School Science Classroom*. Liaoning Normal University.

Zhao, J. (2019). *Research on the Implementation Status of the Science Education under the New Curriculum Standard* (p. 75).

Zhong, Z. (2005). How to Develop Learners' Higher-order Thinking skills? *Journal of Distance Education*, *4*(1), 78.