Doctoral Dissertation

STEM Education for the Crucial Thinking Skills in Indonesian Science Education

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ABSTRACT

This study has confirmed three essential areas of the current condition of STEM education in Indonesia: Essential skills “crucial thinking skills”; instructional design of STEM education “STEM content integration, real-world application, scaffolding”; and the effectiveness of STEM education. These three essential areas were addressed in the research questions: RQ1: What are the most crucial thinking skills for students in science education?; RQ2: To what extent is the instructional design of STEM education (STEM content integration, real-world application, and scaffolding) in Indonesia based on teachers’ views?; RQ3: How does STEM education influence the crucial thinking skills of students in Indonesia?

Firstly, the essential skill in this study was focusing on the crucial thinking skills. It was found through systematic literature review that students are success in developing some skills, however, certain crucial skills are also found. The issue in skills development raises important questions regarding the crucial skills in the cognition stage among the common skills in science education-Science Process Skills, Critical Thinking Skills, and Reasoning Skills-. SPS focus on the whole learning process that consisted of basic and integrated SPS. Based on the findings in this systematic review, the crucial subskills in SPS are Inference, Measuring, Identifying & controlling variable, Definition operational variable, and Explanation, which mostly consisted of the integrated domain. Also, CTS focus on the evaluation of the learning process with crucial skills, including Interpreting data, Inference, and Evaluation. In addition, all skills in RS are an essential element in the learning process and were found as the crucial domain. Further, through identifying the skills’ relationships which were divided into five groups based on their similarity, researcher revealed that the crucial skills existed in Group I, II, II and IV. In conclusion, based on this finding, most of the crucial thinking skills of the students in science education existed in reasoning skills’ domain which covered all reasoning skills, the integrated science process skills and three of critical thinking skills.

Secondly, the instructional design of STEM education was confirmed in three parts through teachers’ perceptions: STEM content integration, real-world application of STEM education, and scaffolding of STEM education. The condition of STEM content in Indonesia is only integrated into two or three subjects. The first finding showed that STEM education does not exist in the university level for the last 30 years based on teachers’ experiences and some of teachers did not know about STEM education before professional development program. In addition, teachers have conducted STEM education without knowing the term STEM education. Yet, the implementation is still limited and depended on the teacher’s interest and

motivations due to unprovided guidance, reference, or instruction. The teachers have confirmed a huge advantages of STEM Education in improving students' quality of knowledge and skills and also mentioned three significant points of STEM education such as “STEM education is interesting”; “STEM education provides hands-on activities”; “STEM education is the most updated learning process”. They believed that STEM education could give a chance for students to explore more based on real-life and also to balance the students’ habits in and outside the classes. Teachers confirmed that STEM education is more appropriate to the current student’ characteristics, especially in high school student. The last part emerged the challenges: (i) engineering becomes the most challenging subject in STEM education, followed by mathematics, technology, and science. Teachers need to realize that engineering is the situated context and the platform in STEM education; (ii) Teachers specify some challenges including time limitation, lacking of teacher awareness, technology. It was found that implementation of STEM education will face time limitation, lacking teacher awareness and technology; (iii) Teachers also mentioned unmatched Indonesian curriculum with STEM education. It was narrowed down to the relationship between national examination goals in Indonesia and STEM education goals in case of content integration;

Thirdly, when comparing the subskills’ mean score between traditional and STEM group, most of the subskills do not have differences even the result of ANCOVA shows the significant value in the effect of STEM education on the crucial thinking skills. However, the data showed a statistically significant difference between pre- and post-test value of hypothetical-deductive thinking skill in STEM group. It is supported by the previous research in revealing the positive impacts of STEM education on hypothetical-deductive thinking skill.

In conclusion, stage 1 and stage 2 resulted in the current conditions of STEM education in Indonesia. They were confirmed through specific crucial thinking skills and teachers’ perception on the instructional design of STEM education. Although stage 3 failed to support the effectiveness of STEM education to solve all crucial thinking skills in Indonesia. However, the mean score in STEM group showed improvement on hypothetical-deductive thinking skills with the significant difference on the score between pre- and post-test. Preparations need to be made and the challenges need to be addressed before the official curriculum from the government is fully implemented.

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DEDICATION

I dedicate this dissertation to my husband Ahmad Eka Siwi, my parents, my family and friends for the encouragement and unconditional support.

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LIST OF ABBREVIATIONS

UNESCO	The United Nations Educational, Scientific, and Cultural Organization
MoEC	Ministry of Education and Culture
MoNE	Ministry of the National Education
SKL	Standar Kompetensi Kelulusan (The standard of graduate competencies)
PISA	Programme for International Student Assessment
OECD	The Organization for Economic Co-operation and Development
ODI	Overseas Development Institute
STEM	Science, Technology, Engineering, Mathematics
SPS	Science Process Skill
CTS	Critical Thinking Skill
RS	Reasoning Skill
MGMP	Musyawarah Guru Mata Pelajaran (Physics Teacher Association)
LCTSR	Lawson’s Classroom Test of Scientific Reasoning
SAPA	Science – A Process Approach
EI	Empirical Inductive
HD	Hypothetical Deductive
NSF	National Science Foundation
SMET	Science, Mathematics, Engineering, Technology

CHAPTER 1 INTRODUCTION

Background of the Study

Curriculum is one of the main components of the education system and plays a significant role in improving the quality of education. It consists of inputs, processes, and outcomes. It is developed dynamically and continuously in a systematic, flexible, realistic, and contextual way. Curriculum should recognize that education in school needs support from family and the community, which are also places of learning (UNESCO, 2011). In Indonesia, curriculum developmemt does not seek to create a single curriculum for all schools. Rather, it can be different for various learning levels of students, with different measurement criteria for each group of students.

The curriculum content must have its foundation in ethics and morals based on religious and other relevant subject matters. The Ministry of Education and Culture (MoEC) oversees the preparation, coordination, facilitation, and execution of curriculum development. Indonesian curriculum has been changed over the years in order to fulfill and accommodate public needs and aspirations and promote citizens' growth, while keeping in tune with the latest developments in science, technology, and culture. Since independence in 1945, the nation's educational curriculum has changed several times, including in 1947, 1952, 1962, 1968, 1975, 1984, 1994, 2004, 2006, and 2013 as shown in Figure 1.

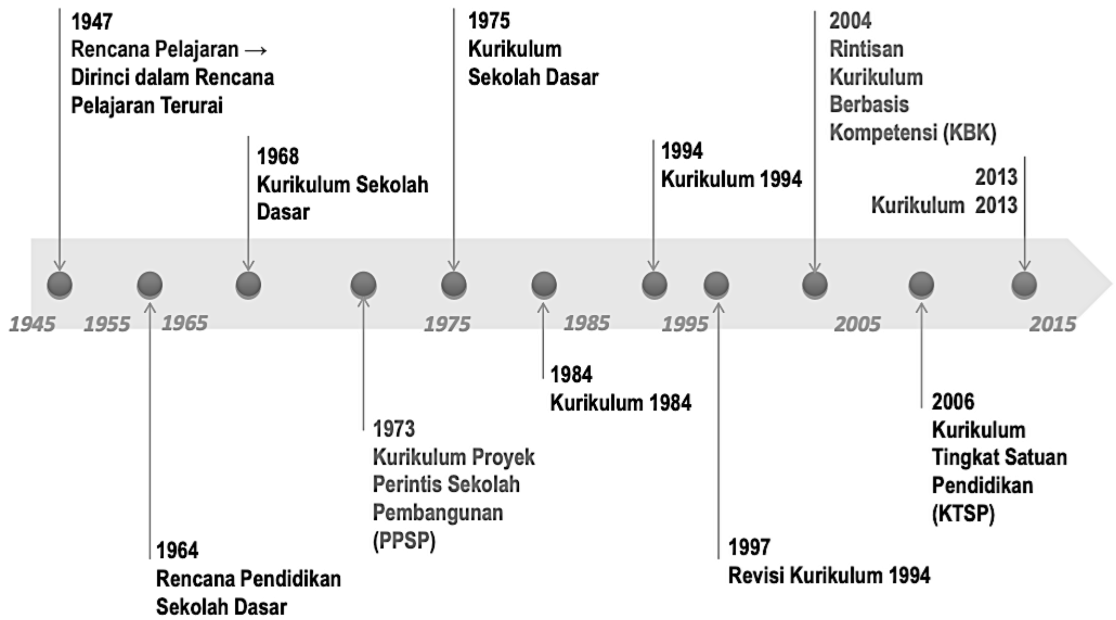


Figure 1. Curriculum Development in Indonesia

Indonesian curriculum has been designed in accordance with Indonesian national principles (the so-called Pancasila) and the 1945 Constitution of Indonesia (MoNE, 2012). The most recently implemented curriculum is the K-13 program in 2013. As part of this program, learners are expected to improve their skills and strike a balance between soft skills and hard skills based on the standard of graduate competencies (SKL), including effective and creative thinking in abstract and concrete domains (Prihantara, 2015).

The government also developed the MoEC stategic plan of 2015-2019 that covered the priority agenda of the K-13 curriculum termed *Nawacita*. The plan aimed to (1) improve the quality of human life in Indonesia by strengthening competencies in applicative fields and bolstering achievements and skills in science, mathematics, and technology, as well as problem-solving abilities based on industry requirements; and (2) enhance productivity and national and international competitiveness through innovation and technological capacity (M. o. E. a. C. MoEC, 2015).

The priority agenda is to strengthen the curriculum and the relevance between the education system and industry needs to improve students' career opportunities in the future by emphasizing skills development. This can be achieved by (1) promoting an interactive learning process that involves students and encourages student creativity and other thinking skills; (2) building 21st century skills in the education sector; and (3) diversifying the curriculum to support the development of students' capability, interest, and intelligence (P. K. d. P. MoEC, 2017). The agenda has emphasized the importance of skills development in the curriculum.

Gropello et al. (2011) have reviewed the main characteristics of and the trends in the demand for skills in Indonesia. The study sought to document the existence of a possible skills mismatch between employer demands and the available supply, the contribution of the education and training sector to this mismatch, and possible measures to improve the education and training system's responsiveness to the needs of the labor market and the economy. Subjective assessments of the difficulties in matching needs with available skills provide evidence that skills are becoming an issue overall in Indonesia.

Thinking skills represent one of the major skill gaps across professional profiles. Five general skill-related priorities can be highlighted for Indonesia. First, the country needs to improve skill measurement to get a fuller understanding of skill needs and gaps. Second, Indonesia needs to urgently address the still unsatisfactory quality and relevance of its education, including higher education. Third, the country needs to set up multiple pathways for skill development. Fourth, the country needs to develop an integrated approach to tackle skill development for youth. Fifth, Indonesia should also tackle labor market constraints, which affect the skill matching process (Gropello, Kruse, & Tandon, 2011). The five priorities emphasize the promotion of skills' capacity and development for Indonesian students and the implementation of an integrated approach to support those skills.

The skills system is regulated by Law 20/2003 on the Education System, Law 12/2003 on Labor and Manpower, Presidential Regulation 8/2012 on the Indonesian National Qualification Framework, Presidential Regulation 9/2016 on Revitalization of SMKs, Government Regulation 31/2006 on National Training System, and Government Regulation 10/2018 on the Indonesian Professional Certification Authority (World Bank, 2019). These regulations have envisaged the significance of an integrated approach in education for skill development in Indonesia

Problem Statement

Even though the government has undertaken this impressive fiscal effort, certain issues may arise during curriculum development. Educational quality and learning outcomes during the New Order improved little if at all over time and compared poorly to other countries (Rosser, 2018). Nowadays, the national examination system is driving curriculum implementation and challenging the educational sector in Indonesia. In particular, the national examination target is pushing science and mathematics education to shift their focus from teaching to learning. Memorizing mathematical and scientific formulae is more common than performing experiments. During the learning process, teachers transfer the knowledge in the textbooks to the students through lectures and drill students on how to answer multiple choice type questions (Bahri, 2013; Hendayana, Supriatna, & Imansyah, 2011).

In fact, the Educational Assessment Center in Indonesia has shown that the average national achievement score in six subjects at the upper secondary level was 69.69 of 100, with science subjects, especially physics and mathematics, posting the lowest average scores in 2019 as shown in Figure 2 (M. o. E. a. C. MoEC, 2019).

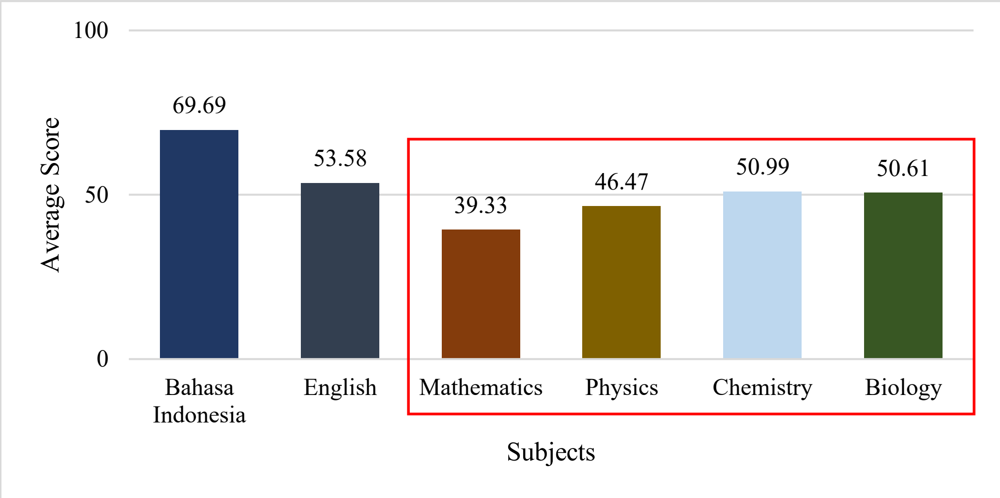


Figure 2. 2019 National Achievement in Indonesia

Science education, which aims to not only build student knowledge but also encourage scientific behavior, has undergone an extraordinary transformation to create the foundation for prosperity and sustainable development. Indonesia's performance in international standardized tests of student achievement from 1999-2015 suggests that little has changed in these respects since the fall of the New Order. Between 2012 and 2015 alone, science performance among 12-year-old students rose by 21 score points. This makes Indonesia the fifth fastest improving nation in terms of the education system among the 72 countries that took part in the Programme for International Student Assessment (PISA), with the country's science performance above that of several other nations that participated in PISA 2015. However, the mean performance of Indonesian science students was lower than the Organization for Economic Co-operation and Development (OECD) average, and more than half of Indonesian students do not possess the adequate skills to compete in the labor market (Gropello, Kruse, Tandon, & Martawardaya, 2010; OECD, 2016).

Indonesian curriculum needs to focus not only on knowledge transfer in education, but also on sustainable development and the building of students' thinking skills and 21st century skills. Traditional science teaching falls short in these respects in Indonesia. It is important to know how to apply scientific concepts to design technologies or products, solve problems, and connect to real world phenomena (Mullis, Martin, Goh, & Cotter, 2016; Mutakinati, Anwari, & Kumano, 2018; P. D. A. Putra, 2017).

The Overseas Development Institute (ODI) (2014) recommended changes to the Indonesian education system, including implementing curriculum and pedagogy reforms, strengthening the teaching force, and supporting decentralization and school-based management (Tobias, Wales, Syamsulhakim, & Suharti, 2014). Students assume real-world connections to what they are learning, or they may completely disengage (El-Deghaidy & Mansour, 2015; Havice, Havice, Waugaman, & Walker, 2018).

Based on these issues, the Indonesian government is adapting STEM education, an interdisciplinary and applied approach to learning science, technology, engineering, and mathematics, to the 2013 curriculum, especially at the upper secondary level (Fransisca, Sisdiana, Dian, & Arie, 2019). The government has made preliminary efforts for the implementation of STEM education, such as conducting STEM training for role model teachers in Indonesia. STEM education is believed to give every student opportunities to improve their skills, abilities, and fundamentals for 21st century learning by utilizing an assortment of movement-based learning models. Students are exposed to a wealth of information, which is one of the major issues in Indonesia, and given chances to solve global challenges (Bybee, 2013; Caprile, Palmen, Sanz, & Dente, 2015; Council, 2011, 2014; Meyrick, 2011; Press, 2005; Scientist, 2013; Shernoff, Sinha, Bressler, & Ginsburg, 2017; Society, 2014; Tanembaum, Gray, Lee, Williams, & Upton, 2016).

In addition, STEM education provides the positive chance in learning and improving thinking skills beyond the content knowledge, such as how to cooperate with the group work process expressing ideas, brainstorming, and creating a product from knowledge, experience, activities and being able to integrate knowledge to apply in daily life, how to use scientific instrumentation appropriately, how to gather and analyse data, how to design methods and problem solved processes, planning and implementing solutions, testing, checking, improving solutions or products and offering solutions to solve problems, (Reynders et al., 2019; Changpetch & Seechaliao, 2020).

Moore et al. (2014) designated a framework for quality STEM education that has six key elements, which are the inclusion of appropriate math and science content based on the grade level, adoption of a student-centered pedagogy, allowance for making mistakes in the learning process, group collaboration, use of an engaging and motivating context, and integration of engineering design challenges. Students engage in hands-on activities that allow them to discover new concepts and develop new understandings. Thus, experimental learning is intentionally used to promote knowledge building, and students are encouraged to test existing ideas by taking things apart, making predictions, observing, and recording their explanations.

In sum, the Indonesian government has had great success in getting children into school and keeping them at school, at least until the end of the compulsory basic education period. However, it has had much less success in ensuring that students receive quality of education (Rosser, 2018). Therefore, STEM education has been utilized for educational development in recent times. However, how and to what extent STEM education can be implemented in Indonesia remains unclear.

CHAPTER 2 LITERATURE REVIEW AND THEORETICAL FRAMEWORK

This chapter outlines the literature review, theoretical framework, research objectives, research questions, and the significance of the study. The literature review was conducted to provide a theoretical basis for this study and also convey what knowledge and ideas have been established by this study and what its strengths and weaknesses are. The study is defined by a guiding concept, including the research questions and objectives. The literature review was conducted in three areas, namely STEM education, skills gained through STEM education, and STEM education systems followed by different countries. The second part outlines the theoretical framework of this study, followed by the research objectives, research questions, and the significance of the study.

Skills Gained through STEM Education

Many psychologists and psychometricians have acknowledged the close relationship between thinking skills and students' overall capacity to learn (Colvin, 1921; Han, 2013). These skills help students in building their knowledge and developing the competence to solve problems and formulate results. The 2013 revision of the Indonesian curriculum required science teachers to integrate thinking skills, including reasoning, processing, and presenting skills, with content learning objectives as part of their general teaching and learning activities. As can be seen from Table 1, the main competencies can be categorized into spiritual, social, knowledge, and skill domains (MoEC, 2016).

Table 1. Main Competency Domains of the 2013 Indonesian National Curriculum

Main Competencies	Description
Spiritual	Refers to having students understand and practice religious beliefs and values in their daily lives
Social	Refers to shared social and cultural values, such as 1. Honesty, 2. Self-discipline, 3. Responsibility, 4. Social awareness,

	5. Cooperation, and 6. Tolerance These values are essential for children to develop and to effectively interact with the environment, family, school, community, state, region, nation, and the world
Knowledge	Refers to understanding, implementing, analyzing, and evaluating factual, conceptual, procedural, and metacognitive knowledge based on interest in **1. Science** **2. Technology** 3. Art 4. Culture, and 5. Humanities Gain insight into how humanity, nationality, statehood, and civilization are related to phenomena and events, and apply knowledge in specific fields of study in accordance with their talents and interests to solve problems
Skills	**Refer to reasoning skills, processing skills, and presenting skills** that are effectively, creatively, productively, critically, independently, and collaboratively reflected in concrete and abstract contexts related to what is learnt in school, and which can be used in accordance with scientific principles

This study focused on two main competencies: knowledge and skills. In Indonesia, knowledge competency relies on science and technology, which are a part of STEM education. As explained in Chapter 1, the Indonesian government has started to introduce STEM education to all stakeholders in education, especially at the secondary level.

Meanwhile, Skills competency relies on reasoning, processing, and critical thinking skills. This study focused only on thinking skills and narrowed them down to three skills: science process skills (SPS), critical thinking skills (CTS), and reasoning skills (RS). These thinking skills are the most important skills for social scientists, teachers, and students in science education (Valentino, 2000) and have become the main objective of education in

Indonesia (Faisal & Martin, 2019). In addition, these skills are an integral part of becoming a scientist and participating in the scientific community and as apprentice scientists, students in science interact with each other in a deeply thinking about the content and realistic contexts where the need for SPS, CTS, and RS can rise organically (Reynders et al., 2019).

Previous studies revealed that the learning process should be conducted via STEM education to challenge students to learn and improve their CTS, RS, and SPS and make themselves better prepared for their career in the future (Fulya & Yusuf, 2017; Naimnule & Corebima, 2018).

It also has been mentioned in the previous chapter that STEM education provides the positive chance in learning and improving these skills beyond the content knowledge, such as how to use scientific instrumentation appropriately, how to gather and analyse data, how to design methods and problem solved processes, planning and implementing solutions, testing, checking, improving solutions or products and offering solutions to solve problems, how to cooperate with the group work process expressing ideas, brainstorming, and creating a product from knowledge, experience, activities and being able to integrate knowledge to apply in daily life (Reynders et al., 2019; Changpetch & Seechaliao, 2020).

Science Process Skills

Science process skills (SPS) are defined as mental abilities that can be practiced, learnt, and developed by children through the learning process and which make them better prepared to meet the challenges of the 21st century (Balfakih, 2010; Osman & Vebrianto, 2013). SPS are essential for acquiring knowledge and ensuring that students have a meaningful learning experience (Lee, Hairston, Thames, Lawrence, & Herron, 2002; Rauf, Rasul, Mansor, Othman, & Lyndon, 2013).

Today, the expression "Science Process Skills" is commonly used, and based on Science – A Process Approach (SAPA), these skills can be classified into basic and integrated SPS. Germann & Aram (1996) and Rauf et al. (2013) define basic skills as the intellectual foundation in scientific inquiry. Basic skills are the preconditions to integrated process skills, which are the final set of skills required for solving problems or performing science experiments. The details of each sub-skill are as follows (Padilla, 1990):

1. Observation: Using intelligence and common sense to gather information about an object or event

2. Inference: Making an “educated guess” about an object or event based on previously gathered data and information
3. Measurement: Using both standard and non-standard measures or estimates to describe the dimensions of an object or event
4. Communication: Using words or graphic symbols to describe an action, object, or event
5. Classification: Grouping or ordering objects or events into categories based on properties or criteria
6. Prediction: Stating the outcome of a future event based on a pattern of evidence
7. Variable control: Identifying variables that can affect an experimental outcome; keeping most of them constant while manipulating only the independent variable
8. Operational definition: Stating how to measure a variable in an experiment
9. Hypothesis formulation: Stating the expected outcome of an experiment
10. Data interpretation: Organizing data and drawing conclusions from it
11. Experimentation: Being able to experiment, including asking a question, stating a hypothesis, identifying and controlling variables, operationally defining those variables, designing an experiment, conducting the experiment, and interpreting the results of the experiment
12. Modeling: Creating a mental or physical model of a process or event

Critical Thinking Skills

There are widely contrasting views about critical thinking skills (CTS). Some highlight the range of perspectives developed around the aspect of education. In summary, CTS can be defined as the mental act of reviewing, evaluating, or appraising something (including a picture, play, piece of information, evidence, or opinion) in an attempt to make judgments or inferences about that something in a rational, reasoned way (McGroger, 2007). CTS are considered to involve intellectually engaged, skillful, and responsible thinking. They facilitate good judgment that requires the application of assumptions, knowledge, competence, and the ability to challenge one's thinking.

CTS require self-correction, the ability to monitor the reasonableness of thinking, and reflexivity. One characteristic that uniquely defines critical thinking is the capability of individuals to step back and reflect on the quality of their thinking (Niu, Behar-Horenstein, & Garvan, 2013). In this study, the researcher adapted the idea of core CTS from Facione (1990), who provided detail descriptors of the associated characteristics. The sub-skills of critical thinking skills are as follows:

1. Interpretation: Grasp and express the meaning or noteworthiness of a wide assortment of circumstances, information, occasions, judgments, rules, strategies, or criteria
2. Analysis: Identify the real inferential relationship among statements, questions, and descriptions to express belief, judgment, experiences, reasons, or opinions
3. Evaluation: Evaluate the validity of articulations or other representations; analyze the coherent quality of the existing or expected inferential relationship among explanations, questions, or other forms of representation
4. Inference: Distinguish and secure components required to draw sensible conclusions; make assumptions and speculations; consider pertinent data; and rationalize the results based on judgments, concepts, questions, or other representations
5. Explanation: Present the results of one's reasoning compellingly and coherently; the sub-skills in this category are the ability to propose and advocate strategies, and protect one's causal and conceptual interpretations of occasions or events
6. Self-regulation: Self-consciously monitor one's cognitive activities, the elements involved in those activities, and the results deduced by analyzing one's inferential judgments with a view toward questioning

Reasoning Skills

The last type of cognitive skills in this study is reasoning skills (RS). Based on psychologists' theory of cognitive development, which is divided into four stages based on age, Lawson (2000) identified reasoning skills in the last two stages: empirical-inductive thought and hypothetical-deductive thought. Empirical-inductive thinking (EI) patterns enable a child to accurately order and describe perceptible objects, events, and situations in his or her world. In this stage, the child starts using language for logical reasoning. Conservation skill is one of the sub-skills of reasoning skills. Hypothetical-deductive (HD) thinking patterns allow young persons to go beyond traditional descriptions and create and test hypothetical explanations (Anton E Lawson, 1995). Given below is a list of the descriptions of each sub-skill in RS based on Lawson (2000).

1. Conservation law (EI): Ability to apply conservation reasoning to perceptible objects and properties (e.g., if nothing is added or taken away, the amount, number, length, weight, etc., remain the same even though the appearance differs)

2. Proportional thinking (HD1): Ability to recognize and interpret relationships between situations described by observable or theoretical variables
3. Identification and control of variables (HD2): A process that includes control of the dependent and independent variables that affect the continuity of the situation during hypothesis testing
4. Probabilistic reasoning (HD3): A situation focused on the division of the number of reiterations of a specific procedure that delivers a specific result when rehashed under the same conditions on countless occasions
5. Correlational reasoning (HD4): Ability to recognize causes in the phenomenon under study by comparing the number of confirming and disconfirming cases of hypothesized relations with the total number of cases
6. Hypothetical-deductive reasoning (HD5): Characteristics of the reasoning process that help in developing and organizing possible solutions to a problem in any domain of life

The Relationships among Three Thinking Skills

As mentioned above, psychologists have established the theory of cognitive development. Piaget (1966) is one of the experts to investigate cognitive development to learn how a child perceives the environment and the world based on his/her observation and interpretation. According to Piaget's theory, cognitive development can be divided into four stages based on age. This study focuses on the last two stages (concrete reasoning and formal operational reasoning), which were previously introduced as EI and HD (Lawson, 1995).

Concrete reasoning (EI) begins from age seven or eight and includes aspects such as naming, describing, and classifying. The epistemology of the concrete reasoning stage thinker is one of observation: What causes events? To find the answer, observe the events. Formal operational reasoning (HD) begins in adolescent and older children. In this stage, some children become increasingly capable of using language to apply the deductive pattern of thinking to hypothetical rather than empirical representations. The epistemology of the formal reasoning stage thinker is vastly different: What causes events? To find the answer, one must first mentally create several possible causes, deduce their potential consequences, and then observe the results of experimental manipulations to support or reject the possibilities (Lawson, 1995). Concrete reasoning and formal operational reasoning form the basis of RS, and this category of skills is typically used by researchers to define more complex skills such as SPS and CTS (Ozgelen, 2012).

Figure 3 shows a model developed for this study that demonstrates the conceptual framework of relationships between SPS, CTS, and RS. This model was developed by taking into consideration the similarity of all sub-skills in SPS, CTS, and RS. This conceptual framework consists of three circles representing the three main categories of skills. The circle with the orange outline represents the area for SPS, the circle with the green outline represents the area for RS, and the one with the blue ouline the area for CTS. The bigger the size of the circle, the greater is the number of sub-skills included. All these circles are included in the cognitive domain, represented by the space within the rectangle. In addition, the blue dots signify the sub-skills of SPS, CTS, and RS. This means that all these skills can be developed or improved through training or high quality learning.

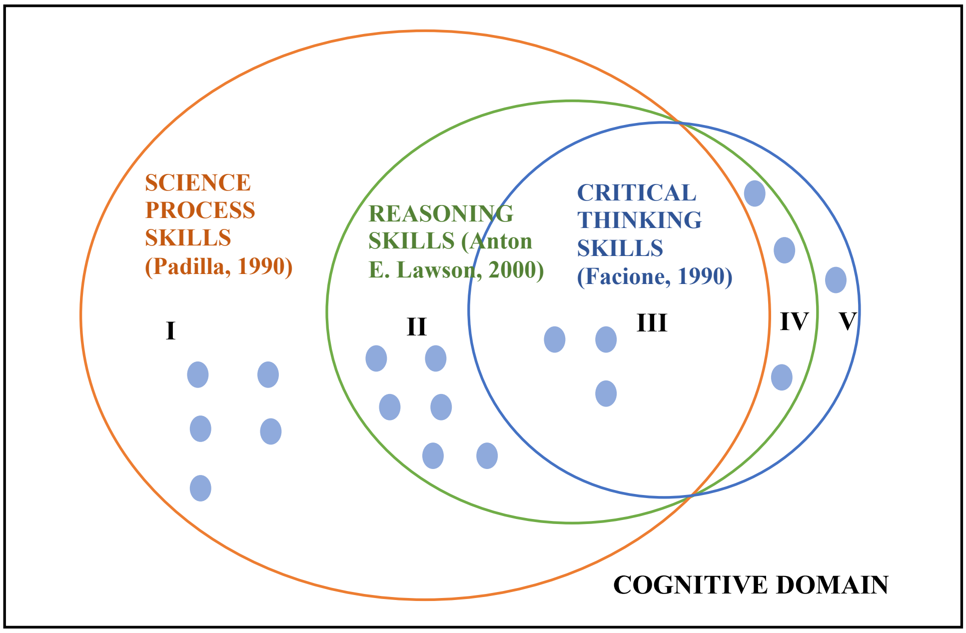


Figure 3. Conceptual Framework of Relationships among Thinking Skills

Based on the model described above, the relationship between the three thinking skills is divided into five groups in accordance with Piaget's theory. The definition and pattern of the skills are listed below.

1. Group I: Observation; Measurement; Communication; Classification; and Operational Definition (EI)
2. Group II: Identification and control of variable (HD2); Prediction skill (HD3); Hypothesis formulation (HD5); Development of experimental design (HD5); Making of model (HD5); and Execution of Experiment (HD5)

3. Group III: Interpretation of data (HD1); Inference (HD4); and Analysis (HD4)
4. Group IV: Simple explanation (conservation/EI); Explanation (HD5); and Evaluation (HD5)
5. Group V: Self-regulation

The first group consists of five sub-skills, namely observation, measurement, communication, classification, and operational definition, which are the characteristics of the basic SPS (Padilla, 1990), but do not include RS or CTS. They become the initial component of the EI stage.

The second group pictures the relationship between SPS and RS, which covers three elements: (i) Identification and control of variable (HD2), which helps students recognize the need to consider all the known variables and design a test that controls all variables; (ii) Prediction skill (HD3), also called probabilistic thinking in reasoning skills, helps students recognize a pattern of evidence (Han, 2013); and (iii) Hypothesis formulation, experimental design/model development, and execution of experiment are covered in hypothetical deductive reasoning (HD5).

The third group talks about the relationship between SPS, CTS, and RS, which consists of two aspects: (i) Interpretation of data (HD1), which covers proportional reasoning to help students recognize and identify the relationships of situations described by observable or theoretical variables. This skill aims to comprehend, organize, and express the meaning or significance of a wide variety of experiences, situations, data, events, judgments, conventions, beliefs, rules, and procedures; (ii) Inference (HD4) and Analysis (HD4) enable students to recognize causes or relations in the phenomenon under study by comparing the number of affirming and disconfirming cases of hypothesized relations with the total number of cases.

The fourth group pictures the relationships between CTS and RS in explanation skills, which are divided into two components: simple explanation (EI), and explanation (HD5) and evaluation (HD5). Simple explanation is also called conservation reasoning and helps students understand concepts and simple propositions related to familiar actions and observable objects, which can be explained in terms of simple associations, and enables them to follow step-by-step instructions as in a recipe, provided each step is completely specified and associate his or her viewpoint with that of another in a simple situation. Explanation skill and evaluation skill (HD5) are involved in testing theories or hypotheses.

The fifth group is self-regulation that helps students organize a strategy to find a solution. Self-regulation is one of the curricular principles that will promote the development of important thinking skills and reasoning patterns needed for freedom of mind (Lawson, 1995). This skill in included in the CTS group, but not in the other two.

In summary, these thinking skills are connected with each other directly and/or indirectly (Lawson, 1995; Ozgelen, 2012). Ozgelen (2012) revealed that the term "formal reasoning skills" is typically used by researchers to define more complex skills and integrated science process skills, which is proved through this model.

Further, the variety of labels and similarities in science process skills, critical thinking skills, and reasoning skills -are confusing to teachers (Bailin, 2002; Lewis & Smith, 1993; Niu et al., 2013; Zimmerman, 2000). There is no previous study that discusses about the thinking skills that should be given top priority in STEM education through the relationship among them. Hence, this study sought to identify the crucial and most highlighted skills among these five groups of skills through systematic literature review.

STEM Education

Definition of STEM Education

In the 1990s, the National Science Foundation (NSF) in the US started using the acronym "SMET," standing for "Science, Mathematics, Engineering, and Technology," which was then changed to STEM in 2001. In the last two decades, the NSF has used STEM to refer to the four separate and distinct fields. In fall 2007, they realized that the acronym STEM is ambiguous, so STEM education was rechristened as "Integrative STEM Education." The notion of integrative STEM education includes approaches to explore teaching and learning between two or more STEM disciplines and within a STEM discipline (Sanders, 2009). The specializations of each subject are explained as follows (Burghardt & Hacker, 2004; Kelley & Knowles, 2016):

1. Scientific inquiry. Preparing students to think and act like real scientists, ask questions, hypothesize, and conduct investigations using standard science practices. *Science concepts: life sciences, physical sciences, chemical sciences;*
2. Technology. As objects, knowledge, activities, and volition. *Technology concepts: technology as tools, technology as ideas, technology as product of science;*
3. Engineering design. As an approach to delivering STEM education creates an ideal entry point to include engineering practices into existing secondary curriculum. *Engineering*

design concepts: models, designs, problem-solving, communicating ideas, planning, implementing;

4. Mathematics thinking. Providing the necessary rationale for students to learn mathematics through valuating design solutions and see the connections between what should be learned in school with what is required in STEM career skills. *Mathematical concepts: numbers, problem-solving, geometry, measurement, representation of math ideas using objects, symbols, and words.*

Nowadays, STEM education is defined depending on the stakeholder. In general terms, STEM education refers to the integration of problem-solving learning with the STEM disciplines (Sari, Alici, & Sen, 2018), and the graduation of students in science, technology, engineering, and mathematics with a future career in these fields. STEM is also connected to economic competitiveness in the global market and maintenance of energy and productivity (Boe, Henriksen, Lyons, & Schreiner, 2011). STEM education combines academic concepts with real-world lessons and connects the school, community, work, and the global enterprise domains with each other (Akaygun & Aslan-Tukak, 2016; Cevik & Ozgunay, 2018; Tsupros, Kohler, & Hallinen, 2009).

As explained in the background of this study, the strategic plan of the MoEC in Indonesia aims to focus on improving students' skills in science, mathematics, technology, and problem-solving based on industry needs through an interactive learning process. Hence, this study defined STEM education as a teaching approach in science at the K-12 education level that seeks to create an interactive learning process by combining science, technology, engineering, and mathematics education with application-oriented techniques and inquiry-based instruction in order to encourage students' creativity and thinking skills. STEM education could make meaningful learning possible and develop relevant career content standards and skills useful in everyday life (John et al., 2018; Maarouf, 2019; Pawilen & Yuzon, 2019; Sari, Alici, & Sen, 2018).

Moore et al. (2014) designated a framework for quality STEM education that has six key elements, which are the inclusion of appropriate math and science content based on the grade level, adoption of a student-centered pedagogy, allowance for making mistakes in the learning process, group collaboration, use of engaging and motivating context, and integration of engineering design challenges.

STEM education provides benefits to students by giving them opportunities to integrate interdisciplinary research topics in their studies (Honey, Pearson, & Schweingruber, 2014; Jacobs & Eccles, 2000). In addition, it plays a key role in achieving critical competencies such as problem-solving skills, social communication skills, technology and engineering skills, and system skills (Jang, 2016). STEM education supports students' explorations, questions, and conversations, and reveals how competent they are in the science, technology, engineering, and mathematics subjects (DeCoito, Steele, & Goodnough, 2016). STEM education is believed to contribute to the development of 21st century skills (Altan, Ozturk, & Turkoglu, 2018).

STEM education has been around for quite a long time, but it was only in 1957 that American educators concurred on the estimation that it is important for giving the US an edge in the worldwide economy (White, 2014). STEM education was implemented only recently in Indonesia due to constrained resources. The idea of STEM education in Indonesia has been gaining ground (Suprapto, 2016).

STEM education has the purpose of (1) furthering students' understanding of each discipline by building on students' prior knowledge; (2) broadening students' understanding of STEM disciplines through exposure to socially relevant STEM contexts; and (3) making the four STEM disciplines and related careers more accessible to and intriguing for students (Wang, Moore, Roehrig, & Park, 2011). STEM education is believed to provide opportunities for more relevant, less fragmented, and more stimulating experiences for learners (Furner & Kumar, 2007), and to eliminate the misconceptions of students about science education (Hasanah, 2020). Previous research has confirmed that STEM education has considerable effects on students' career choices in the future.

Previous study confirmed that STEM education had considerable effects on the students' choices towards career insterest towards their future. It can make meaningful learning possible, develop important careers content standards and useful skills in everyday life (John, Siburna, Wunnava, Anggoro, & Dubosarsky, 2018; Maarouf, 2019; Pawilen & Yuzon, 2019; Sari, Alici, & Sen, 2018). Pawilen & Yuzon (2019) established six important things that need to be considered in designing STEM education as a part of effective curriculum:

1. Interest of the students on the topics and activities
2. Availability of materials to be used
3. Appropriateness of the topics and activities to the learners
4. Relevance to learners' daily lives

5. Connection of the contents and activities to the K-12 curriculum
6. Integration of science, technology, engineering, and mathematics

STEM Education and Inquiry-based Instruction

Thibaut et al. (2018) pointed out that STEM education at the secondary education level is based on social constructivism theories, which state that learning is socially situated and knowledge is built through interaction with others based on one's existing ideas and experiences. They mentioned several categories of STEM educational practices, including inquiry, which is also supported by Blue (2014). The term "inquiry" has been used to characterize good practices in both teaching and learning in STEM education (Rocard et al., 2007). Inquiry-based instruction is defined as a pedagogical approach that combines the curiosity of students and scientific method to enhance skills development during STEM learning (Blue, 2014; Warner & Myers, 2012).

In inquiry-based instruction, students engage in hands-on activities that allow them to discover new concepts and develop new understandings. Thus, experimental learning is intentionally used to promote knowledge building, and students are encouraged to test existing ideas by taking things apart, making predictions, observing, and recording their explanations. Although inquiry-based instruction originated in science education, where students are usually required to engage in authentic science practices (e.g., planning and designing experiments and collecting data), it is not restricted to this domain and also occurs in mathematical or technological contexts (Satchwell & Loepp, 2002).

As illustrated in Figure 4, scientific inquiry is at the center of STEM education and the process must become an integral part of STEM education (Carin, Bass, & Contant, 2005). Students engage in five activities when teachers implement inquiry-based instruction: question; investigate; use evidence to describe, explain, and predict; connect evidence to knowledge; and share findings.

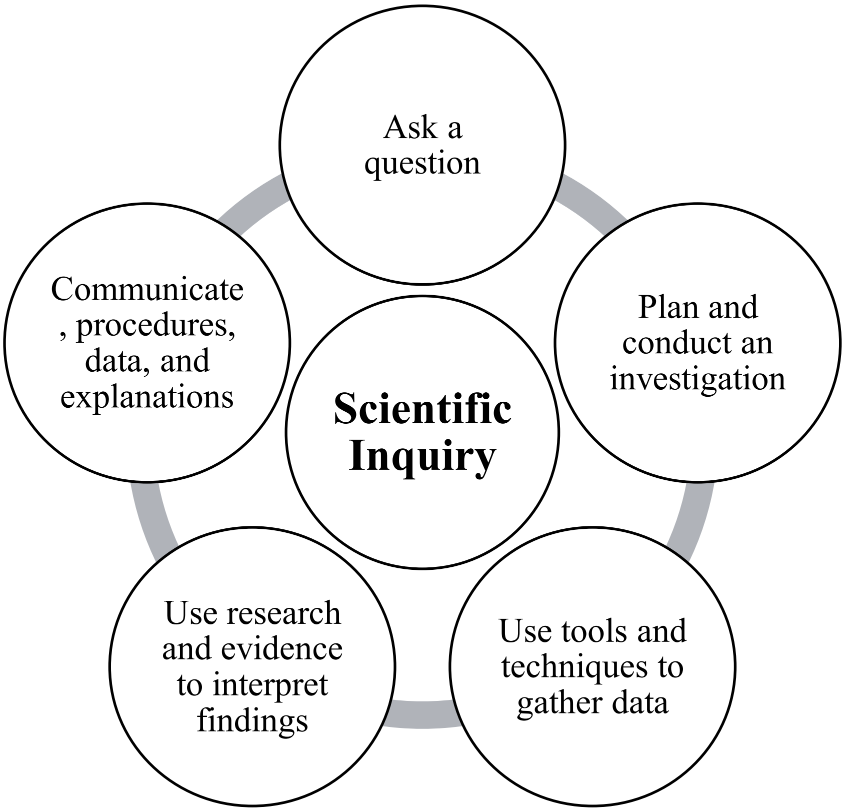


Figure 4. Science Education must Expand its Curriculum to Connect with Technology, Engineering, and Math to Develop a Cogent STEM Curriculum

Students must be oriented to the entire gamut of scientific method right from identifying the problem to experimenting, reporting the results, and evaluating the effectiveness of the method. Table 2 shows how scientific inquiry allows teachers to address specific elements of scientific inquiry. When teachers integrate the essential elements of scientific inquiry into STEM education, students develop a scientific way of thinking (Fang, Lamme, Pringle, & Abell, 2010).

Table 2. Essential Elements of Scientific Inquiry

Elements:	Notes:
Planning	
Generate research question	Finalize the thing to be studied
Design studies	Plan the look and function of the study
Identify variables	Name the thing(s) to be investigated (location, environment)
Plan procedures	Outline the step-by-step process of the study

Control variables	Control the study variables under examination
Plan measures	Decide whether you will collect scores and what the time and length of the study should be
Implementing	
Begin procedures	Follow your plan
Make observations	Collect data
Reporting	
Explain results	Write a report or prepare a presentation
Translate observation into data sources	Develop data collection forms, processes
Find flaws in the research	Critique the study in terms of its limitations
Draw inferences about research questions	Use data and analysis to figure out answers to your questions
Generate an explanation	Write a report of what you found out, as a result of your study
Argue an interpretation	Make a case for your way of thinking
Develop a theory	Identify the prevailing principle that emerges
Disseminate findings in multiple studies	Submit research reports on different aspects of the study
Study research reports for information pertinent to their study	Read research conducted by others on the same or similar topic

Science teachers and researchers have diverse interpretations of effective forms of inquiry. Previous research has proposed a model consisting of four phases that seek to encompass STEM education. In the first phase (inquiry invitation), the teacher proposes an engineering-based real world problem that serves as a context to teach science-related content. During the second phase, students perform a guided inquiry, wherein they conduct different experiments using scientific practices and technology, and interpret data using mathematics. The third phase consist of an open inquiry, during which students discuss the results obtained in the guided inquiry and propose new research questions necessary to solve the initial problem. The fourth and final phase (inquiry resolution) requires the design or implementation of a solution, which could be technological in nature. In this way, students begin to explore engineering design, linking engineering and science. Table 3 shows how STEM disciplines are emphasized during the four phases in the proposed model of inquiry (Toma & Greca, 2018). The details of the learning process in this study will be elaborated in the next chapter.

Table 3. Inquiry Phases and the Relationship with STEM Disciplines

Coupled Inquiry	STEM disciplines
INQUIRY INVITATION Science content is introduced through real-world problem	SCIENCE-ENGINEERING Real world problem related to an engineering challenge
GUIDED INQUIRY Students perform guided experiment following teacher instruction	SCIENCE Application of scientific methodologies in order to address the scientific concepts needed to solve the problem MATHEMATICS Data analysis and interpretation TECHNOLOGY Handling of devices and instrument for the design of experiments, data gathering and analysis
OPEN INQUIRY Students keep addressing the initial problem through experiments that are not guided by the teacher	SCIENCE, TECHNOLOGY, ENGINEERING, MATHEMATICS Students discuss the result obtained and they identify better ways to improve their design in order to solve initial problem
INQUIRY RESOLUTION Solving the initial problem	ENGINEERING Students design or implement the technological device that solves the initial problem; using the scientific concepts developed previously and, in this wat, linking engineering and science TECHNOLOGY Students propose possible technological applications in real world situations of the scientific concepts addressed throughout the

	inquiry. Students communicate their result and offer possible resolutions of the initial problem

STEM Education among the Countries

The Implementation of STEM Education

The implementation of STEM education in an educational system that has a very special and discipline-based structure requires deep restructuring of the curriculum and lessons (Louis S. Nadelson & Anne L. Seifert, 2017). It requires numerous materials and resources for students (Pawilen & Yuzon, 2019; Stohlmann, Moore, & Roehrig, 2012). STEM education has been applied to the elementary to higher education field for decades in the USA and recently adapted by many Asian countries including Indonesia (Fransisca et al., 2019; Hwang & Taylor, 2016; Koonce, Zhou, Anderson, Hening, & Conley, 2011; Radloff & Guzey, 2016). It has become more prominent for the researchers, the government and teachers. The believes are the understanding of student are not the primary intention in education, how do students have adequate skills to face their career in the future should be more significant and it is promoted through implementing STEM education.

Obviously, serious efforts should be arranged to transform traditional learning approaches to STEM education, especially in faces several difficulties in preparing the readiness of STEM implementation in the countries (Awad, Salman, & Barak, 2019; Shumow & Schmidt, 2013).

Factors in Implementation of STEM Education

Researcher listed factors in the implementation of STEM education into three broad categories (intrinsic, extrinsic, and institutional) that is formatted in the table 4 below. Each domain was defined as follows; (1) intrinsic factor that is related to personnel of the teacher as well as student, for example quality of teaching, educator's personal experience and awareness, attitudes, beliefs, practice or preparation and resistance; (2) extrinsic factor which is resulted from inadequate and or inappropriate configuration of infrastructure for teacher such as gender, racial, time, access, support, resource, training for educator, cultural; (3) institutional factor is specific to curriculum, policy, technology, as well as organizational sustenance in the education field (Maguire, 2008; Shadle, Marker, & Earl, 2017).

Table 4. Category of Factor in STEM Education

No.	Domains	Intr.	Ext.	Inst.

	Factor	
1.	Teacher`s education (need for course and workshop to face the real-world problem solving through teamwork)	*
2.	Instructional challenges (Lack of pedagogical skills)	*
3.	Insufficient assessment methods and processes	*
4.	Poor content preparation, delivery, and method of assessment, they are not familiar enough with the content	*
5.	Expectations of Content Coverage (much material to be understood and choose to skip)	*
6.	Teachers' effort Does not fit in with standards/state testing. They need the effort to implement a very different structure in an educational system	*
7.	Outcome expectations	*
8.	Lack of knowledge on how to effectively spread the use of currently available and tested research-based instructional ideas and strategies	*
9.	Lack of teachers' time (too busy with substantial teaching loads and research responsibilities, lack of time for collaborative planning with other instructors & Instructional time)	*
10.	Teachers' STEM knowledge	*
11.	Teachers' professional mindset	*
12.	Lack of hands-on activities for students	*
13.	Inappropriate level for students so they found the difficulty	*

14.	Little research effort devoted to the study and improvement of STEM change strategies or models, lack of research collaboration	*
15.	Departmental Norms (traditional method as the norm and no local role models to offer supportive; Loss of autonomy: force faculty to teach and assess all the same way, less individual control of content and methods)	*
16.	Time structure in the class (limited)	*
17.	Gender and racial imbalances, especially in engineering	*
18.	Poor preparation and shortage in supply of qualified STEM teachers, Lack of investment in educator's professional development	*
19.	Students are pulled out for support	*
20.	Family background and support (Everyone in the family was discouraging about going to STEM, no family members had previously attended college or work in STEM field)	*
21.	Social support (Each region has different provided education, it makes student discourage to learn if the student is too tricky to find STEM education, or High schools do not offer classes needed for STEM fields necessary in college, such as calculus, or No motivation to pursue STEM careers in high school)	*
22.	Lack of resources (materials and tools, poor condition of laboratory facilities and instructional media	*
23.	The current culture is unsupportive	*

24.	Class size and room layout (a Large number of students)	*
25.	Lack of support from the school system, Not enough support from administrators	*
26.	Does not fit in the curriculum	*
27.	Insufficient number of specialized classes were offered at the high school	*
28.	Conflicts with institutional rewards/priorities	*
29.	Departmental divisions	*
30.	The uncertainty of goals (on retention) and vague goals of the faculty	*
31.	Challenges in engagement across faculty rank	*
32.	Misalignment with accreditation requirements	*
33.	School structure and organization (school schedule and various goals of schooling must be reorganized)	*
34.	Pre-service education (various STEM disciplines exist in many institutions that delivering pre-service education)	*

As listed in Table 4, intrinsic domain emerges with 13 factors which means the implementation of STEM education in the countries are mostly influenced by this factor domain. Two main point are found in this domain: teacher point and student point. Teachers' factors talk about teachers' knowledge on the content of STEM education, the pedagogical knowledge, education of the educator, and time management. In a STEM class, teachers are the "most knowledgeable other" or "master thinker" in the classroom context. Their role is to guide students in the scaffold use of STEM literacies to develop authentic habits of thinking toward STEM solutions.

More specifically, teachers are the model for (a) questioning, wondering, and curiosity, (b) brainstorming processes, (c) developing plan, (d) generating a litany of educated guesses about a particular situation, and (e) examining theories, ideas, and potential solutions espoused by others. In essence, the teacher is a very knowledgeable individual and thinker who does not regurgitate the thoughts and ideas of others (Blue, 2014).

STEM education requires more understanding of each subject compared to ordinary instruction. It is transformed from conventional teaching, teacher-centred learning, to active student-centred learning. McDonald (2016) summarize the pedagogical instructions, including Inquiry; Argumentation and reasoning; Digital learning; Computer programming and robotics; Integration of some STEM content; Cooperative learning; Student-centered; Hands-on; Assessment; 21st century skills, have been shown to be effective in promoting student engagement and achievement in STEM disciplines. STEM education also refers to solving problems that draw on concepts and procedures from mathematics and science while incorporating the teamwork and design methodology of engineering and using appropriate technology (J. Smith & Karr-Kidwell, 2000).

Since the existence of teachers are vital in this system, it is required for them to put more efforts and commitment on STEM education in order to maximize the output of this system (Chachashvili-Bolotin, Milner-Bolotin, & Lissitsa, 2016; Coppola, Madariaga, & Schnedeker, 2015; Ejiwale, 2013; Louis S Nadelson & Anne L Seifert, 2017; Shadle et al., 2017; Shernoff et al., 2017).

An understanding of STEM education should be had by the teachers to established across domains and by engaging a community of practice (Kelley & Knowles, 2016). A capacity to collaborate, and to think creatively and innovatively of one’s teaching is minimal requirement (Beswick & Fraser, 2019; Eckman, Williams, & Silver-Thorn, 2016). Any coordination of the teaching across science, technology, engineering and math makes some knowledge demand in relation to the other disciplines in order to have sensible conservations for coordinated planning (Ostler, 2012).

Gurol (2004) & Tasdemir (2003) in Konokman, et al., (2017) confirmed that no matter how well the new system in education is, it will not achieve its objectives unless teachers as implementers can fulfil their task efficiently. Teachers are seen not only as the active curriculum implementers but also as primary elements giving feedback about the current curriculum to improve it. Teachers are expected to manage the curriculum at least implementation level by mastering principles of teaching, significances, contents, learning-teaching approaches, educational technologies, and evaluation processes.

Some studies have been investigating teachers' perception in STEM education for in-service teachers as well as pre-service teachers (Calisici & Sumen, 2018; El-Deghaidy & Mansour, 2015; Erdogan & Ciftci, 2017; Hammack & Ivey, 2016; Pitiporntapin, Chantara, Srikoom, Nuangchalerm, & Hines, 2018). Erdogan & Ciftci (2017) and Calisici & Sumen (2018) have worked with pre-service teachers perceptions on STEM education through training and activities in Turkey. The result informed that pre-service teachers show positive attitudes toward STEM education.

Besides, the pre-service teacher should be supported through the seminar, conference, etc. to have the necessary content knowledge and pedagogical knowledge related to STEM education and provided with the required resources and materials. On the other hand, El-Deghaidy & Mansour (2015), Hammack & Ivey (2016) have studied in-service teachers perception in Egypt and the United States of America. The benefit of STEM education has been emphasized the contribution to creative thinking and creativity. They also recommended a STEM professional development program in order to strengthen the content, curricular, and pedagogical knowledge to teach STEM effectively.

These studies have been conducted in US, Egypt and Turkey and none of the study have been done in Indonesia. They also focused on one experience such as pre-service experience or in-service experience only (Calisici & Sumen, 2018; El-Deghaidy & Mansour, 2015; Erdogan & Ciftci, 2017; Hammack & Ivey, 2016; Pitiporntapin et al., 2018) and without considering STEM challenges (Calisici & Sumen, 2018; Hammack & Ivey, 2016; Pitiporntapin et al., 2018; Srikoom, Hanuscin, & Faikhamta, 2017).

Theoretical Frameworks of the Study

This study adapted the STEM education framework from the Global STEM Alliance (GSA) that aimed to identify the best practices in science, technology, engineering, and mathematics. It reflects current education research and draws on innovative and effective practices employed around the world. This framework, as pictured in Figure 5, has three essential areas: Essential Skills, Instructional Design, and Implementation (Wee & Ling, 2019).

In this study, these essential areas in the theoretical framework will serve as a guide to determine the current state of STEM education in Indonesia. The details are explained below.

1. Essential Skills: “Crucial thinking skills”

   In this study, the researcher focused only on the essential skills, i.e., the crucial thinking skills. Essential skills mean the competencies that students must develop to thrive in the modern workplace. Several essential skills are included in this framework, such as critical thinking skills, problem solving skills, creativity, communication, collaboration, data literacy, and digital literacy and computer science. However, there is no clarity on which essential skills are “crucial” or should be given “first priority” in STEM education, especially in Indonesia. Therefore, this study aimed to identify the essential skills through a systematic literature review of crucial thinking skills.

2. Instructional design of STEM education

   Instructional design consists of research-based pedagogy, STEM content integration, real-world application, project- or problem-based learning, scaffolding, assessment, cultural sensitivity and relevance, and technology integration. However, in this study, the researcher covered only three elements, which are STEM content integration, real-world application, and scaffolding. STEM content is presented in an integrated, interdisciplinary approach, wherein students have multiple opportunities to apply STEM skills and knowledge in the context of STEM activities, problems, and/or practices. STEM content also needs to be embedded in or related to the real-world scenarios with materials that provide clear guidance for teachers on scaffolding STEM education.

3. Evidence of effectiveness

   Evidence of effectiveness is the last element analyzed in the STEM education framework. This framework includes six aspects, such as evidence of effectiveness, accessibility, alignment with local contexts, professional development and learning support, access to materials and practitioner support, and scalability. However, this study sought to determine only the effectiveness of STEM education in terms of its impact on crucial thinking skills in Indonesian science education.

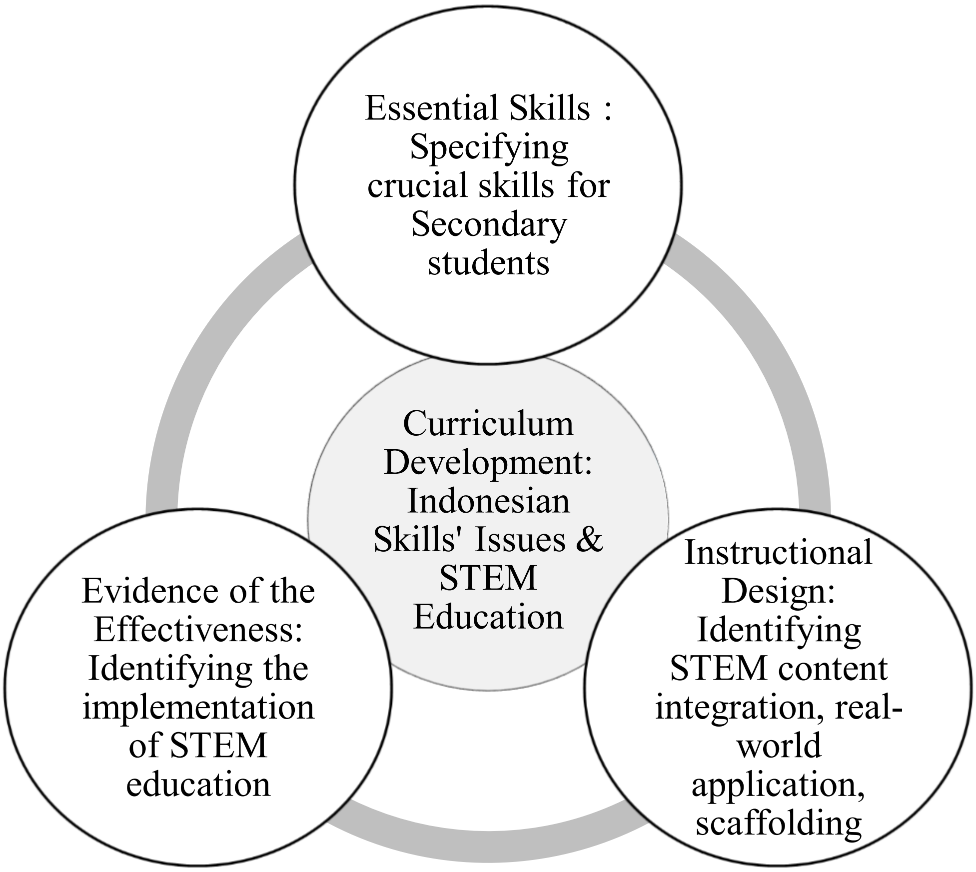


Figure 5. Theoretical Framework

Research Objectives

In order to support curriculum development, this study aimed to investigate the current state of STEM education in Indonesia and to what extent the implementation of STEM education can solve the current issues faced by the country, especially in physics education at the upper secondary level.

This study identified three essential areas concerning the current state of STEM education in Indonesia: essential skills in terms of "crucial thinking skills," instructional design, and the effectiveness of STEM education. Therefore, there were three stages in this study. The first stage was related to selected skills in science education based on the current issues in Indonesia. The skills that should be given precedence, especially in science education, are still unclear. So, the researcher narrowed down the list of most common skills to include the most crucial thinking skills through systematic review. The second stage examined the current state of STEM education in Indonesia based on instructional design factors: STEM content integration, real-world application, and scaffolding. In this stage, the researcher first conducted a "STEM professional development program" for science teachers to ensure that they have gotten the initial knowledge and understood STEM education before examining their views on STEM.

The third stage sought to determine the effectiveness of STEM education in influencing students' crucial thinking skills in science education. One of the science teachers who participated in the STEM professional development program was asked to help in the learning process.

The overall objective of the study was to summarize the current state of STEM education in Indonesia under three essential areas (1st stage: essential skills; 2nd stage: instructional design; and 3rd stage: evidence of effectiveness). Therefore, in order to achieve the main goal, three sub-objectives were established, which are indicated in the following list:

RO1: To specify the crucial thinking skills in science education through systematic literature review;

RO2: To identify the instructional design of STEM education (STEM content integration, real-world application, and scaffolding) in Indonesia for secondary level;

RO3: To determine the effect of STEM education on the crucial thinking skills for secondary level.

Research Questions

To achieve the objectives, the author set up the following research questions:

RQ1: What are the most crucial thinking skills for students in science education?

RQ2: To what extent is the instructional design of STEM education (STEM content integration, real-world application, and scaffolding) in Indonesia based on teachers' views?

RQ3: How does STEM education influence the crucial thinking skills of students in Indonesia?

Significances of the Study

In general, the contribution of this study is precisely valuable for all stakeholders in implementing STEM education especially for developing countries including Indonesia. From the government' view, the study findings provide the pictures on which points in "teacher and student" that they have to work on before deciding to fully implement STEM education in Indonesia as well as inform on how STEM education influences the students' skills based on the priority goals of MoEC 2015-2019.

Further, from the teachers' view, they acquire knowledge about STEM education and the implementation in the class, especially in science classes. From students' view, they develop a new experience during the learning process which direct and/or indirectly affects their thinking skills. In addition, Identifying and addressing potential skills will be a key, not only to boosting job creation in the formal sector, but also to support higher productivity, competitiveness and growth.

Composition of the Dissertation

The dissertation consisted of seven chapters as pictured in Figure 6. Chapter 1 described the issues in this study through the background and problem statement. In this chapter, the national as well as international issues such as "the mean performance of Indonesian science education still that got lower than the Organization for Economic Co-operation and Development (OECD) average and more than half of Indonesian students do not possess adequate skills to compete in the labor market" got attention from researcher and become the basic problem of this study.

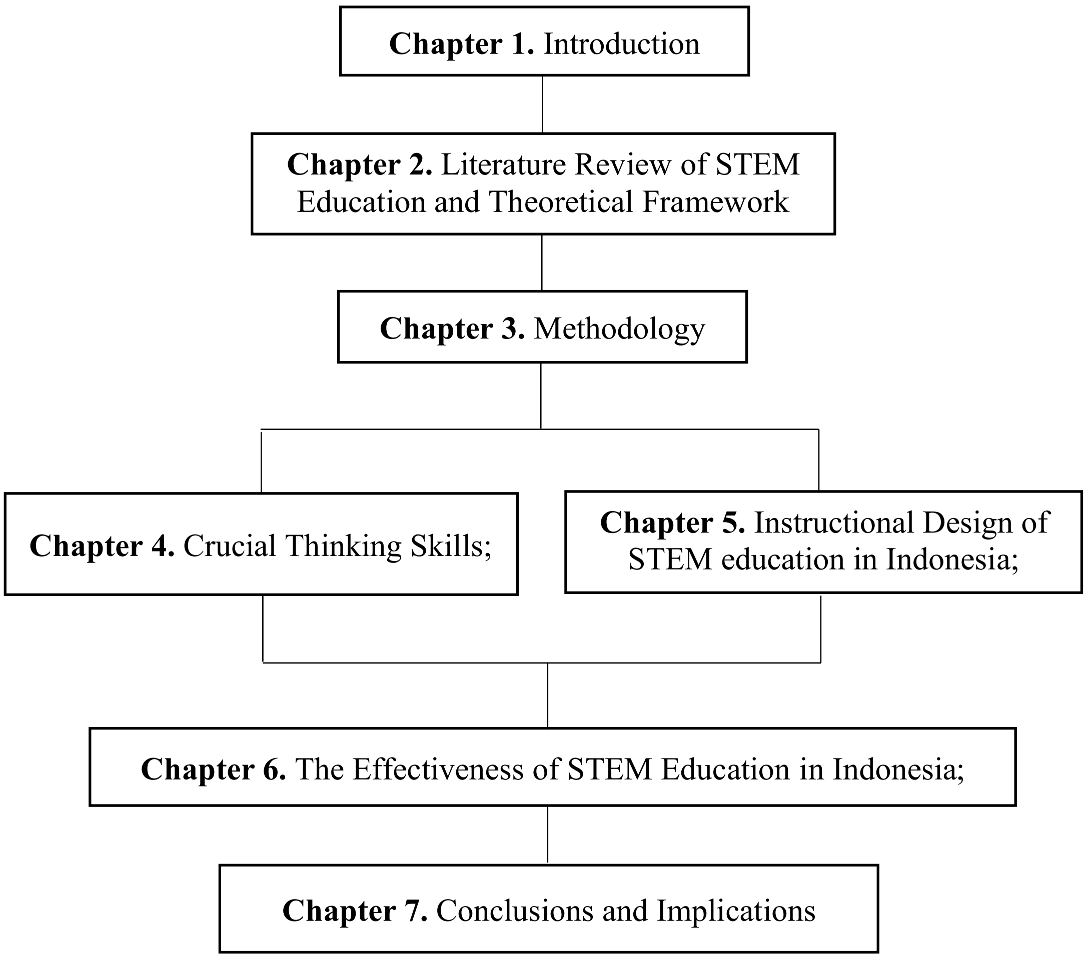


Figure 6. Composition of the Dissertation

Chapter 2 dealt with the literature reviews in this study, theoretical framework, research objectives, research questions, the significance of this study, and composition of the dissertation. These literature reviews were conducted in order to provide the theoretical base and the nature of this study and to convey what knowledge and ideas have been established on this study and what the strengths and weaknesses are. These literature reviews were defined by a guiding concept including the issue of this study and research objective. There were four literature review starting from skills gained through STEM education, STEM education, and STEM education among the countries. The second part was the theoretical framework of this study. This study adapted the STEM education framework from The Global STEM Alliance that aims to identify the best practices in science, technology, engineering, and mathematics. It reflected the current education research and drew on innovative and effective practices employed around the world. This framework has three essential areas: *Essential skills* (Crucial thinking skills)*, Instructional design of STEM education (*STEM content integration, real-world application, Scaffolding*),* and *Evidence of effectiveness* (Implementation of STEM education). All these three essential areas were utilized to figure out the important information/conditions that should be known before STEM education is fully implemented in Indonesia. The main focus of this study was to investigate the current condition of STEM education and how far STEM implementation can solve the current issues in case of skills' development in Indonesia, especially in physics education for upper secondary level. This study has confirmed three essential areas based the theoretical framework divided into three stages with three sub-objectives: RO1: To specify the crucial thinking skills in science education through systematic literature review; RO2: To identify the instructional design of STEM education (STEM content integration, real-world application, and scaffolding) in Indonesia for secondary level; RO3: To determine the effect of STEM education on the crucial thinking skills for secondary level.

Chapter 3 explained overall methodology from three sub-objectives based on the theoretical framework and the relationships among three stages. The first stage aimed to find out the current crucial skills in science education that can be solved through the implementation of STEM education in Indonesia. In this stage, researcher has conducted a systematic literature review. This stage consisted of several processes: (a) creating the detail of criteria for inclusion and exclusion empirical studies. In total, there are eight inclusion criteria that have be decided. (b) conducting literature search in electronic databases based on the inclusion criteria. 288 articles were eligible for full-text screening and at the end, only 78 articles that were ready to be reviewed (c) finalizing the literature research and reading the detail of each study; (d) identifying the pattern of the studies especially for the author and sample size, country, institution, measurement, instrument, and finding; (e) synthesizing the pattern in order to answer the research questions. The second stage purposed to understand the current condition of instructional design in Indonesia. In total, 14 teachers were interviewed using six questions about the processes of teachers on knowing, understanding, and implementing STEM education in their classes. The qualitative data analysis was used inductive approach and conducting traditionally with five processes: organizing data, identifying framework, sorting data, descriptive analysis arrangement, and finishing with the second order analysis. The third stage aimed to reveal the effectiveness of STEM education in solving the current crucial thinking skills in Indonesia. The total participants were 63 secondary level students in the grade X that were divided into two groups; STEM and traditional group. These two groups were taught by the same teacher and learned the same within the four times of teaching session. 24 items of two-tier multiple-choice from LCTSR are utilized to measure students' reasoning skills. For further analysis, researcher analyzed with SPSS program using Analysis Covariance and t-test analysis. The relationship among three stages can be considered through how these stages were supporting each other's to reveal three essential areas of STEM implementation Indonesia with considering teachers and students condition as the significant element in education. The findings from the first stage was utilized to identify the implementation of STEM education in Indonesia, the second stage's findings were utilized to reveal the instructional design of STEM education in Indonesia from teachers' perspective, and the last findings were revealed the effect of STEM education in Indonesia through applying the first and the second stage finding and participant.

Chapter 4 explained the details of the first stage "essential skills (The crucial thinking skills)" of the study through methodology and the result a systematic literature review. This data collection aimed to find out the most crucial thinking skills that should be developed in the students' cognition domain, particularly among science process skills, critical thinking skills and reasoning skills that were included to the list of essential skills in STEM education. Further, the relationships of these three skills were divided into five groups based on Piaget's theory: (1) SPS group, (2) combination between SPS and RS, (3) combination among SPS, RS, and CTS, (4) combination between RS and CTS, (5) CTS group. Then, this systematic review identified, selected, synthesized, and appraised previous studies in skills development that meet prespecified inclusion criteria. Based on the data analysis, the first crucial skills came from SPS group including defining operational variables skill and measuring. The second is crucial skills between SPS and RS including Identification & controlling variable, Formulating hypothesis, Experimental design, Conducting Experiment. The third is crucial skills among SPS, RS, and CTS that consisted of Interpreting data, Inference, and Analysis skills. The fourth crucial skill exists in the group combination between RS and CTS consisted of Simple explanation (conservation reasoning/EI), Explanation, Evaluation. In conclusion, most of the crucial thinking skills in science education were covered in the first, second, the third, and the fourth group and narrowed down to the reasoning skills domain only.

Chapter 5 employed phenomenological research in order to understand teacher's perceptions related to their understanding and experiences of STEM education in Indonesia through preconditions “STEM professional development program”. This was related to *Instructional Design:* the second essential area in the STEM education framework that consisted of three points (STEM content integration, real-world application, and scaffolding). This stage was conducted purposive sampling from 38 sub-districts in Pangkep to explore the diversity and discover comprehensive data. Researcher has conducted semi-structured interview for five new teachers and nine experienced teachers with six questions related to how science teachers’ experiences on knowing, understanding, implementing STEM education in their classes as well as STEM education challenges. All teachers revealed that STEM education does not exist in the university level in Indonesia for the last 30 years based on their teaching experience. Currently, STEM education was adapted by the government and delivered by supervisors through MGMP meeting. Teachers realized that STEM education is interesting; provides hands-on activities; the most updated learning process. Teachers also confirmed a huge advantages of STEM Education. Otherwise, government and all facilitators in education, including teachers, must give more awareness in supporting the capabilities to prepare STEM implementation in the schools. Some challenges and limitations of STEM education in Indonesia were revealed by the teachers. In conclusion, all these findings revealed teachers’ confirmation about STEM content that should be presented as interdisciplinary approach and embedded in or related to real-world scenarios. However, the education materials in Indonesia did not include enough guidance for teachers and/or embedded student support to implement STEM education in the school and other challenges might be appear during the implementation.

Chapter 6 figured out how the implementation of STEM education was affected to the crucial thinking skill in Indonesian’s science education. This was the last essential area of STEM education framework. In this stage, the total participants were 63 secondary level students in the grade X that are divided into two groups; STEM and traditional group. Researcher used 24 items of two-tier multiple-choice from LCTSR. This test can be utilized to assess students’ scientific reasoning skills in six domains: conservation laws, proportional reasoning, control variables probabilistic reasoning, correlation reasoning, and Hypothetical-deductive reasoning. These skills were found also as the most crucial skills in science education in chapter 4. When comparing the subskills' mean score between traditional and STEM group, most of the subskills do not have differences even the result of ANCOVA shows the significant value in the effect of STEM education on crucial thinking skills. STEM education can support the crucial thinking skills only for hypothetical-deductive thinking skill. It showed through the improvement of mean score and a statistically significant difference between pre- and post-test value of this skill in the STEM group. A lot of factors revealed as the cause the findings such as teachers' understanding on STEM education and also the STEM educational design in this study that mostly focused on the experiment part.

Chapter 7 elaborated the overall conclusions, the implications, the limitations and the recommendations of this study based on the findings in chapter 4, 5, and 6. Stage 1 and stage 2 resulted in the current conditions of STEM education in Indonesia. They were confirmed through specific crucial thinking skills and teachers' perception on the instructional design of STEM education. Although stage 3 failed to support the effectiveness of STEM education to solve all crucial thinking skills in Indonesia. However, the mean score in STEM group showed improvement on hypothetical-deductive thinking skills with the significant difference on the score between pre- and post-test. Preparations need to be made and the challenges need to be addressed before the official curriculum from the government is fully implemented.

CHAPTER 3 METHODOLOGY

This chapter elaborates the overall methodology of the research, which was split into three stages based on the three sub-objectives: RO1: To specify the crucial thinking skills in science education through systematic literature review; RO2: To identify the instructional design of STEM education (STEM content integration, real-world application, and scaffolding) in Indonesia for secondary level; RO3: To determine the effect of STEM education on the crucial thinking skills for secondary level.

Overall Research Design

The first, second, and third sub-objectives were realized in the first, second, and third stages, respectively. As shown in Figure 7, each sub-objective had a different research design. However, the relationships between the three stages will be explained and the findings will be integrated in one frame under the conclusions on the current state of STEM education in Indonesia.

The first stage aimed to identify the crucial skills in science education that can be achieved through the implementation of STEM education in Indonesia. In this study, the researcher conducted a systematic literature review, which involved several steps: (a) establishing the criteria for inclusion and exclusion of empirical studies: a total of eight inclusion criteria were decided upon; (b) conducting literature search in electronic databases based on the inclusion criteria: a total of 288 articles were eligible for full-text screening, but only 78 articles were ready to be reviewed; (c) finalizing the literature search and reading the selected studies; (d) identifying the characteristics of the studies, especially with respect to the authors, sample size, country, institution, measurement, instrument, and findings; and (e) synthesizing the characteristics to answer the research questions. In the process of analyzing the data, the researcher finalized the literature search and completed the review of the selected articles. Further, the researcher conducted data extraction and made an overview with the characteristics, including author and sample size, country, institution, design (measurement & instrument), and findings. The approach adopted for data analysis and reporting was a narrative content analysis based on expert recommendation from Knoll et al. (2018) because the other studies analyzed were too heterogeneous in terms of study design or outcome (Popay et al., 2006).

The second stage sought to understand the current state of instructional design of STEM education in Indonesia. In total, 14 teachers were interviewed using six questions related to the processes regarding learning, understanding, and implementing STEM education in their classes. The qualitative data analysis used a deductive approach that traditionally goes through five steps: organizing data, identifying the framework, sorting data, descriptive analysis arrangement, and completion with second order analysis. The focus areas of this qualitative study were based on teachers' experiences, opinions, knowledge, and beliefs. Previous research has suggested measurement through preconditions such as professional development programs (Calisici & Sumen, 2018; El-Deghaidy & Mansour, 2015; Erdogan & Ciftci, 2017; Hammack & Ivey, 2016).

The third stage aimed to reveal the effectiveness of STEM education in terms of realizing the current crucial skills in Indonesia. The total participants were 63 secondary level students in grade X who were divided into two groups: STEM group and traditional group. The STEM group utilized STEM education with inquiry-based learning, while the traditional group used conventional instruction with discovery-based learning. A total of six meetings were conducted for each group, including pre- and post-test. These two groups were taught by the same teacher and learned the same concepts in the four teaching sessions. Twenty-four items of the two-tier multiple-choice type from the Lawson Classroom Test of Scientific Reasoning (LCTSR) were utilized to measure the students' reasoning skills. The researcher used the SPSS program for analysis of covariance and t-test analysis.

This study examined the perspectives of teachers in the second stage and of students in the third stage. The researcher intended to obtain the teachers' perceptions on STEM content integration, real-world application, and scaffolding based on their understanding and experiences. This study conducted purposive random sampling from 38 sub-districts in Pangkep Regency, which is at a distance of about 49 km from Makassar, the capital city of South Sulawesi, Indonesia, to ensure diversity and obtain comprehensive data. The participating teachers were divided into two groups: new teachers (0 to 10 years of teaching experience) and experienced teachers (more than 10 years of experience). Thus, five new teachers and nine experienced teachers were interviewed. All of the respondents had an academic degree in science and taught physics at the senior high school level. To ensure anonymity, the names of all participants have been coded.

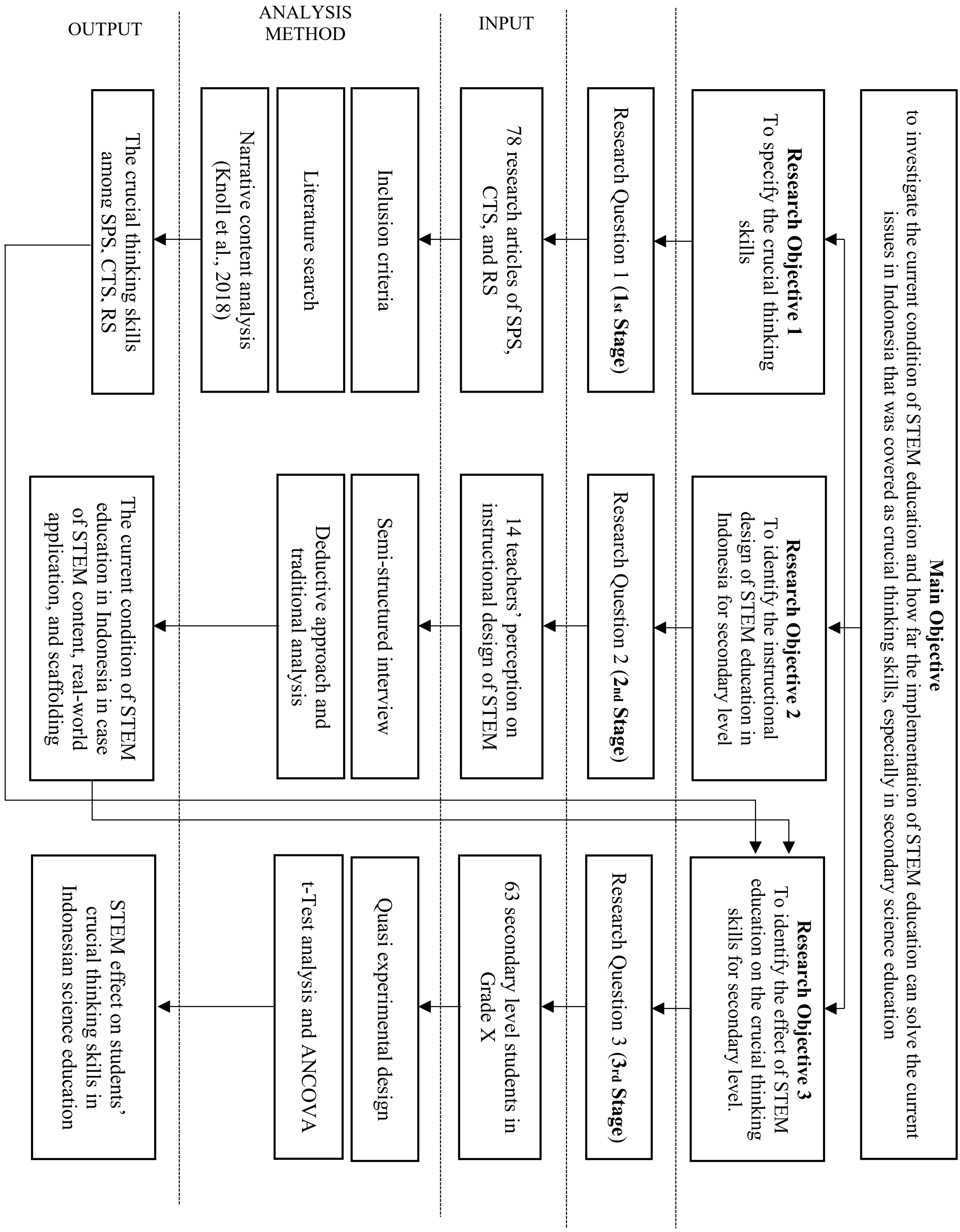


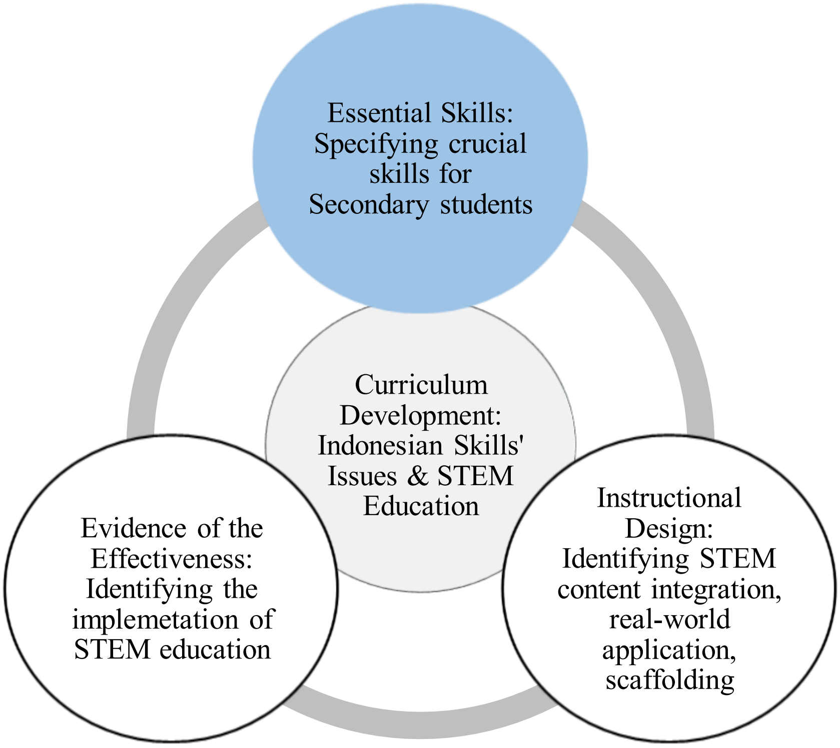
Figure 7. Research Design

The 63 student participants were secondary level students in grade X at a public school in Pangkep Regency, South Sulawesi, Indonesia. Purposive random sampling was used to obtain a sample with the same background.

The relationship between the three stages can be viewed in terms of how these stages supported each other to shed light on the three essential areas of STEM education in Indonesia with an emphasis on the perspectives of teachers and students. The findings from the first stage were utilized to identify the effectiveness of STEM education in Indonesia, the second stage findings were utilized to determine the current state of STEM education in Indonesia from the teachers' perspective, and the last stage findings applied the first and second stage findings to reveal the effect of STEM education in Indonesia. The details of the relationship between these three stages are portrayed in Figure 6.

CHAPTER 4 CRUCIAL THINKING SKILLS

Methodology of the First Stage



The first stage aimed to shed light on the first essential area of STEM education based on the theoretical framework, i.e., the crucial thinking skills that should be realized through STEM education. In this stage, a systematic literature review was conducted. The review identified, selected, synthesized, and appraised studies that met the pre-specified inclusion criteria for the purpose of investigating the status of current research based on research objectives (Knoll et al., 2018). This stage consisted of several steps:

1. Establishing criteria for inclusion and exclusion of empirical studies;
2. Conducting literature search in electronic databases based on the inclusion criteria;
3. Finalizing the literature search and reading the selected studies;
4. Identifying the characteristics of the studies; and
5. Synthesizing the characteristics in order to answer the research questions.

Inclusion Criteria

Figure 8 shows the flow of the literature search and the process of exclusion of articles based on the literature search using keywords, title and abstract, and full-text article assessment. The last selection was based on the established inclusion and exclusion criteria, which are as follows:

1. The studies should be empirical research involving qualitative (e.g. observation) and/or quantitative (e.g. experimental, quasi-experimental, survey research, correlational) analysis;
2. The studies should be focused on measures for improving cognitive skills in science education (SPS, CTS, and RS);
3. The skill dimension for each cognitive skill should be based on the models provided by Michael J. Padilla for SPS, Peter Facione for CTS, and Anton E. Lawson for RS, or at least clearly explain the sub-skills;
4. The studies' results should clearly outline the detailed progress of each sub-skill so as to enable the research questions of this systematic review to be answered;
5. The samples in the studies should be students from the primary level to university level;
6. The studies should have been published as a journal article or conference proceedings;
7. The studies should have been published in English or Indonesian;
8. There was no time restriction for the studies.

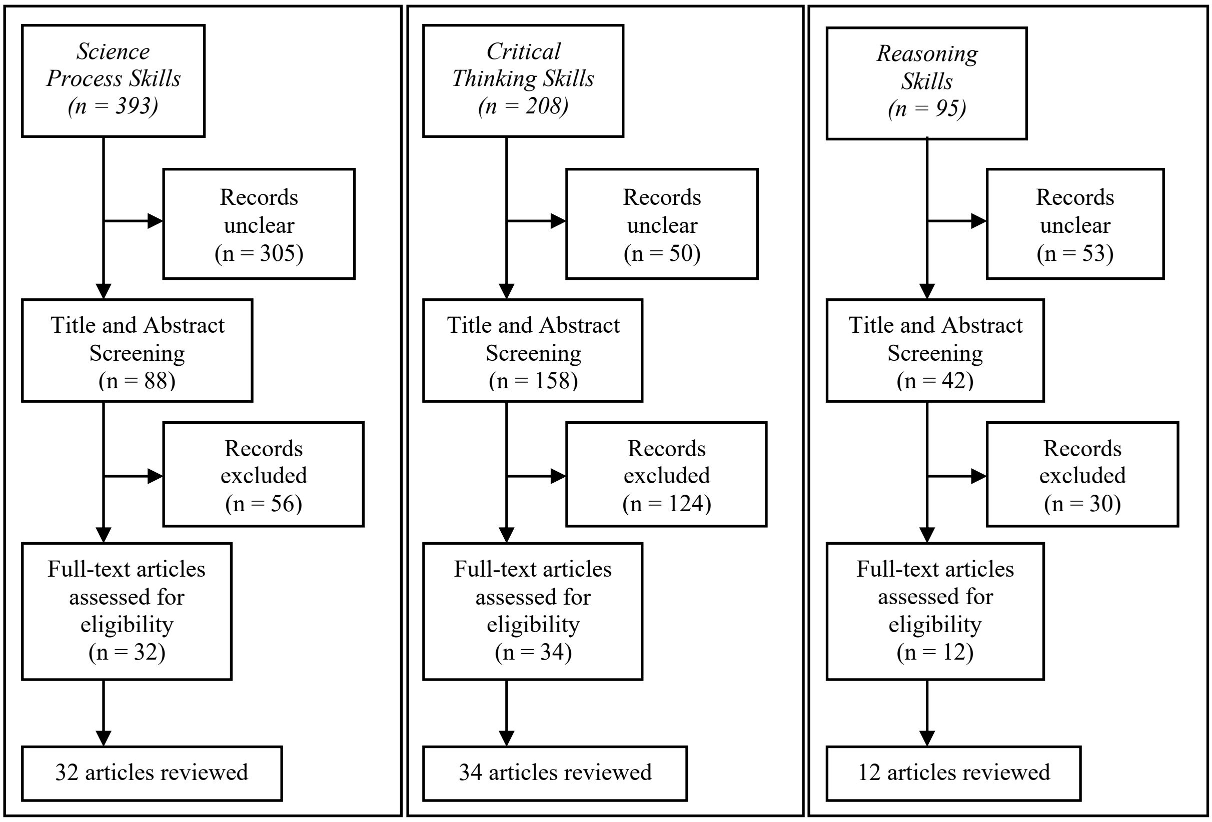


Figure 8. Flow Chart of Literature Search

Literature Search

The literature search was conducted in ERIC (Education Resources Information Center), Scopus, Web of Science, and Google Scholar using keywords like "Cognitive," "Process skill," "Critical thinking skill," "Reasoning skill," "Science education," and "Students" without any time restriction.

The initial search in the electronic databases yielded 696 potential articles. The researcher subsequently conducted title and abstract screening and shortlisted 288 articles for full-text screening, which were eventually narrowed down to 78 articles, including 32 articles for science process skills, 34 articles for critical thinking skills, and 12 articles for reasoning skills.

Analysis Procedures

As part of the data analysis, the researcher finalized the literature search and read the selected articles. Further, the researcher extracted relevant data and made an overview with the following characteristics:

1. Author and sample size,
2. Country,
3. Institution,
4. Design (measurement & instrument), and
5. Findings.

The approach adopted for data analysis and reporting was a narrative content analysis based on the expert recommendation from Knoll et al. (2018) because the other studies analyzed were too heterogeneous in terms of study design or outcome (Popay et al., 2006).

To address the first research question, the findings from the selected studies in this systematic review were synthesized to fit into patterns. The final findings were divided into two categories: non-crucial and crucial. The non-crucial sub-skills category covered all sub-skills that received a high mean score or exhibited the greatest improvement during the intervention or whose rate or frequency of occurrence among the study participants was high.

The crucial sub-skills category included those sub-skills that had the lowest mean score or exhibited the least improvement (decreasing), or which occurred at a low rate or frequency. Further, based on the model in Figure 4, the researcher analyzed whether the crucial sub-skills in one of the three thinking skill domains overlapped with the crucial sub-skills in the other skill domains and how they were related. All data were then organized manually using Microsoft Excel.

Result and Discussion

Previous studies have tried to identify improvements, particularly in science process skills (Akinbobola & Afolabi, 2010; Huppert, Lomask, & Lazarowitz, 2002; Lati, Supasorn, & Promarak, 2012; Ongowo & Indoshi, 2013; Rauf et al., 2013), critical thinking skills (Duran & Dokme, 2016; Shin, 1998; Zhou, Huang, & Tian, 2013), and reasoning skills (Mendoza, Diaz, & Meneses, 2018; Piraksa, Srisawasdi, & Koul, 2014; Remigio, Yangco, & Espinosa, 2014), and have confirmed the importance of each skill.

However, the questions of whether those skills are related when it comes to the development of the cognitive domain of students, and to what extent students are provided with opportunities to develop the skills needed to thrive in the modern workplace remain unanswered. None of the studies conducted so far identify the most crucial skills in science education.

Crucial Domains in Science Process Skills

In the area of science process skills, 32 studies—four studies at the primary level, 20 studies at the secondary level, and eight studies at the university level—were reviewed, with the essential characteristics shown in Table 5. In terms of the total sample, 6,248 participants were involved in these studies. The selected studies mostly came from Turkey and Asian countries, such as Indonesia, Malaysia, and Thailand. Twenty-eight studies were conducted quantitatively with experimental, pre-, true, and quasi-experimental designs.

Table 5. The Characteristics of 32 Included Studies in SPS

Author (Sample Size)	Country	Institution	Design (Measurement Instrument)	Findings
(Ozturk, Tezel, & Acat, 2010) (n = 828)	Turkey	Eskisehir Osmangazi University	• Experimental • Questionnaire • Grade 7th, Secondary school	Recording data skill, Observation, Classification, Measure, and data explication, Formulating a hypothesis, Modelling, Decision skill has been achieved at a high level;

				Inference, Experimenting, Changing variable and controlling, Number and space relations, Prediction, and Variable definition have been achieved at a middle and low level.
(Zeidan & Jayosi, 2015) (n = 159)	Palestine	Al-Quds University	• Experimental • Questionnaire • Grade 10th, Secondary school	Observation skill, Predicting, Measuring, Data interpreting, Communicating, Hypothesizing skill get high rank; **Classifying skill, Controlling variable, and Experimentation skill** get low rank.
(Yilmaz, 2019) (n = 332)	Turkey	Karamanoglu Mehmetbey University	• Experimental • Questionnaire • Grade 3rd 4th, Primary school	Observation, classification, communication skills got a high level; **Inference, measurement, and prediction skills** got a low level.
(Kamba, Giwa, Libata, & Wakkala, 2018) (n = 203)	Nigeria	Kebbi State University of Science and Technology	• Experimental • Questionnaire • Secondary school	Observation skill, measuring, predicting, and data interpreting skill got high rank; **Communicating skills, Classifying, Controlling**

				variables and Hypothesising, and Experimentation skill got a low rank.
(Duruk, Akgun, Dogan, & Gulsuyu, 2017) (n = 307)	Turkey	Adiyaman University	• Survey • Method and document analysis • Grade 5th, 6th, 7th, 8th, Primary school	Observation skill, Communicating, Classifying, Interpreting data, Experimenting, and Modelling skill was the most represented skill; **Inferring, Measuring, Predicting, Controlling variables, Defining Operationally, Formulating Hypothesis skill**s were the least.
(Tekerci & kandir, 2017) (n = 40)	Turkey	-	• Quasi-experimental • Questionnaire • Preschool and Nursery classes	Observation, Comparison, Classification, Measurement, Communication, Inference, Predicting skill were a statistically significant difference.
(Ting & Siew, 2014) (n = 119)	Malaysia	Universiti Malaysia Sabah	• Quasi-Experimental • Questionnaire • Grade 5th Primary school	Observing skill, Communicating, and Classifying skill has the greatest improvement; **Inferring skill, Predicting, and Controlling variables skill** have the least increment.

(Sahhyar & Febriani, 2017) (n = 62)	Indonesia	State University of Medan	• Quasi-Experimental • Observation sheet • Grade 11th, Secondary school	Observing skills, Questioning, Interpreting, Classifying, Predicting, Communicating, Planning, Applying concept, Generalizing skill had the highest percentage of average; **Inferring skill and Making hypothesis skill**s had the lowest percentage of average.
(Gultepe & Kilic, 2015) (n = 34)	Turkey	Dumlupinar University	• Quasi-experimental • Questionnaire • Grade 11th, Secondary school	Forming data table skill, Graph drawing, Graph interpretation, Determining the variables and building up a hypothesis, changing, and controlling variables skill got the significant effect of the treatment; **Designing experiments skill** had no statistically significant difference.
(Harahap, Nasution, & Manurung, 2019) (n = 94)	Indonesia	State University of Medan	• Quasi-Experimental • Questionnaire • Biology program Faculty of Mathematics and Science,	All results in all indicators of science process skills showed significant differences among students; except for **asking questions skill, planning an experiment, and**

			University level	**implementing concept skills**.
(Aydogdu, 2017) (n = 1272)	Turkey	Afyon Kocatepe University	• Experimental • Questionnaire • Primary school	Primary students gained the highest success percentage in prediction skill, classification, observation; The lowest success percentage was showing in **communicating skill, measurement, and inference skill**.
(Irwanto, Saputro, Rohaeti, & Prodjosantoso, 2019) (n = 43)	Indonesia	Yogyakarta State University	• Quasi-experimental • Questionnaire • University level	Students obtained the highest mean rank in Formulating hypothesis skill, Investigating, Inferring, Interpreting skill; The lowest in **Communicating skill, Measuring, Experimenting, Identifying and Controlling variables, and Observing skill**.
(Beaumont-Walters & Soyibo, 2010) (n = 305)	Jamaica	-	• Experimental • Questionnaire • Grade 10th, Secondary school	The subjects' mean score was low and unsatisfactory; their performance in decreasing order was: **interpreting data, recording data, generalizing,**

				formulating hypotheses, and identifying variables.
(Turpin & Cage, 2004) (n = 531)	Louisiana	Louisiana Department of Education	• Quasi-Experimental • Questionnaire • Grade 7th, Secondary school	Identifying experimental question, Designing investigation, Graph data skill was a statistically significant difference in comparing both groups; **Formulating hypothesis skill** was no statistically significant difference in comparing both groups.
(Ogan-Bekiroglu & Arslan, 2014) (n = 17)	Turkey	Marmara University	• True experimental • Questionnaire • Pre-service physics teacher	Identifying variables skill, Defining operationally, Stating hypothesis skill was in the highest rank of performance; **Designing experiment skills and data and graph interpretation skills** were in the lowest rank of performance.
(Wahyuni, Indrawati, Sudarti, & Suana, 2017)	Indonesia	Jember University	• Pre-experimental • Observation sheet • Grade 7th, Secondary school	Observation skill, Measuring and Communicating skill were in the excellent category; **Formulating question skill, Formulating problems, Formulating conclusions, Classifying**

				and analyzing data, Apply concept, and Making predictions skills were in less category.
(Ates, 2004) (n = 103)	Turkey	Bolu Abant Izzet Baysal University	• Experimental • Questionnaire • Junior college	Defining operationally, Interpreting and graphing data skill was a statistically significant difference between transitional and concrete reasoners; **Identifying & controlling variables skill and Stating hypothesis skill**s were not statistically significant differences between both reasoners.
(Saribas & Bayram, 2009) (n = 54)	Turkey	Marmara University	• Quasi-experimental • Questionnaire • University level	Identifying variables, Operationally defining, Designing investigations were statistically significant difference means can be improved easier comparing to **Identifying and stating hypotheses skill as well as Graphing and Interpreting data**.
(Mutlu & Temiz, 2013)	Turkey	Nigde University	• Experimental	The variations are observed to be

(n = 496)			• Questionnaire • Secondary school	statistically meaningful in terms of responding variable identification, controlled variable identification, formulating a hypothesis, variable modification, and control skill; Otherwise, **identifying manipulated variable skills and interpreting data skill**s was not statistically meaningful.
(Osman & Vebrianto, 2013) (n = 96)	Malaysia	The National University of Malaysia	• Quasi-experimental • Questionnaire • Secondary school	A significant difference between groups in classifying skill, predicting, and inference; However, there are no significant differences in **observing and communication skills**.
(Jeenthong et al., 2013) (n = 73)	Thailand	Mahidol University	• Quasi-experimental • Questionnaire • Grade 11th, Secondary school	Collect data skill, and Design experiment skill got the higher mean scores; **Identifying variables skill and Pose question and hypothesis skill** got the lowest mean score.
(Siahaan, Suryani, Kaniawati, Suhendi, &	Indonesia	Indonesia University of Education	• Pre-experimental • Questionnaire	Only predicting skill was in the high criteria; **Observing skill, summarizing,**

Samsudin, 2017) (n = 23)			• Grade 7th, Secondary school	**communication, and classifying skill**s was in moderate criteria.
(Delen & Kesercioglu, 2012) (n = 290)	Turkey	Michigan State University	• Experimental • Questionnaire • Grade 6th seventh 8th,	From three grade, the result shows that Predicting skill, Formulating a hypothesis, and Classifying skill were the highest represented skills; **Observing skill, Interpreting data, Inferring, Defining Operationally, and Experimenting skills** were the lowest represented skills.
(Ongowo & Indoshi, 2013) (n = 10)	Kenya	Maseno University	• Observation • School records • Secondary school	Observing skill, Inferring, Communicating, Interpreting data, Experimenting skill was the rated highest frequency; **Measuring skill, Classifying, Predicting, Controlling variables, Defining Operationally, Formulating hypothesis skills, and Formulating model skill**s were rated the lowest.

(Lati et al., 2012) (n = 63)	Thailand	Ubon Ratchathani University	• Experimental • Questionnaire • Grade 11th, Secondary school	Only Identifying and controlling variables skill was identified as "excellent"; **Defining operationally skill, Formulating a hypothesis, Experimenting, and Interpreting data and Drawing conclusion skills** were identified as "good and fair."
(Akinbobola & Afolabi, 2010) (n = 10)	Nigeria	University of Uyo	• Observation • School records • Secondary school	Observing skill, Calculating, Recording, Communicating, Manipulating skill was rated highest; **Measuring skill, Comparing, Contrasting, Drawing, experimenting & Investigating, Graphing, Interpreting, Deducing, and Formulating model skill**s were rated lowest.
(Rauf et al., 2013) (n = 24)	Malaysia	Universiti Malaya	• Experimental • Questionnaire • Grade 8th, Secondary school	Observing skill, Communicating, and Experimenting skill was the highest frequency and percentage that inculcate in the lesson;

				Classification skill, Measurement and use of the number, Making inference, Making a prediction, Interpreting data, Defining operationally, Controlling variables, and Forming hypothesis skills were the lowest frequency and percentage.
(Huppert et al., 2002) (n = 181)	Israel	University of Haifa Tivon	• Experimental • Questionnaire • Grade 10_{th}, Secondary school	Measurement skill and Graph communication skill were a statistically significant difference in two cognitive stages; **Classification skill, Interpreting data, Prediction, Evaluating hypothesis, Controlling variables, Selecting useful data, and Designing an experiment skill** were not significant in two or all cognitive stages.
(Laksono, Suyanta, & Rizky, 2018) (n = 61)	Indonesia	Yogyakarta State University	• Observation • Observation sheet	Indicator percentage of Observing skill, Planning experiment, Classifying, Organizing data in the table, and Identifying variable skill was higher

			• Grade 10th, Secondary school	than **Inference and Communicating skill.**
(Maison, Darmaji, Kurniawan, & Indrawati, 2019) (n = 130)	Indonesia	Jambi University	• Correlational research • Observation sheet • University level	**Overall basic science process skills** of physical education students of Jambi University are still considered not good.
(Prihatnawati, Amin, & Muhdhar, 2017) (n = 138)	Indonesia	State University of Malang	• Quasi-experimental • Questionnaire • Grade 8th, Secondary school	Observing skill and Conducting experiment skills got the highest average; meanwhile, **Preparing hypothesis skills, Collecting data skills, and Formulating conclusion skill**s got the lowest average.
(Molefe, Stears, & Hobden, 2016) (n = 75)	South Africa	University of KwaZulu-Natal	• Quantitative research with a qualitative component • Questionnaire • University level	Observing skill, Interpreting data skill, Classifying skill, Formulating a hypothesis, Interpreting data, and Experimenting skills are chosen as the most important by the participant; **Inferring skill, Measuring skill, Communicating, and Predicting skill**s are chosen as the least

	important in science process skills.

The findings of the studies are summarized in Figure 9. It can be seen that observation skills, communication skills, measurement skills, classification skills, prediction skills, and model making skills are included in the non-crucial category. On the other hand, six sub-skills emerged as crucial thinking skills. Inference skills ranked the highest, with 70.6% of the 17 studies identifying this skill as a crucial domain in science process skills (Aydogdu, 2017; Delen & Kesercioglu, 2012; Molefe et al., 2016; Ozturk et al., 2010; Ting & Siew, 2014; Yilmaz, 2019).

It was found that in 65.0% of 20 studies, variable identification and control skills got low mean scores and low percentages of correct answers, making them a crucial category (Ates, 2004; Beaumont-Walters & Soyibo, 2010; Huppert et al., 2002; Jeenthong et al., 2013; Mutlu & Temiz, 2013; Ongowo & Indoshi, 2013; Yilmaz, 2019; Zeidan & Jayosi, 2015). For operational definition skill, 60.0% of 10 studies revealed a low mean score (Delen & Kesercioglu, 2012; Duruk et al., 2017; Huppert et al., 2002; Lati et al., 2012; Ongowo & Indoshi, 2013; Rauf et al., 2013), Hypothesis formulation also emerged as a crucial category in 61.9% of 21 studies (Ates, 2004; Jeenthong et al., 2013; Saribas & Bayram, 2009; Turpin & Cage, 2004).

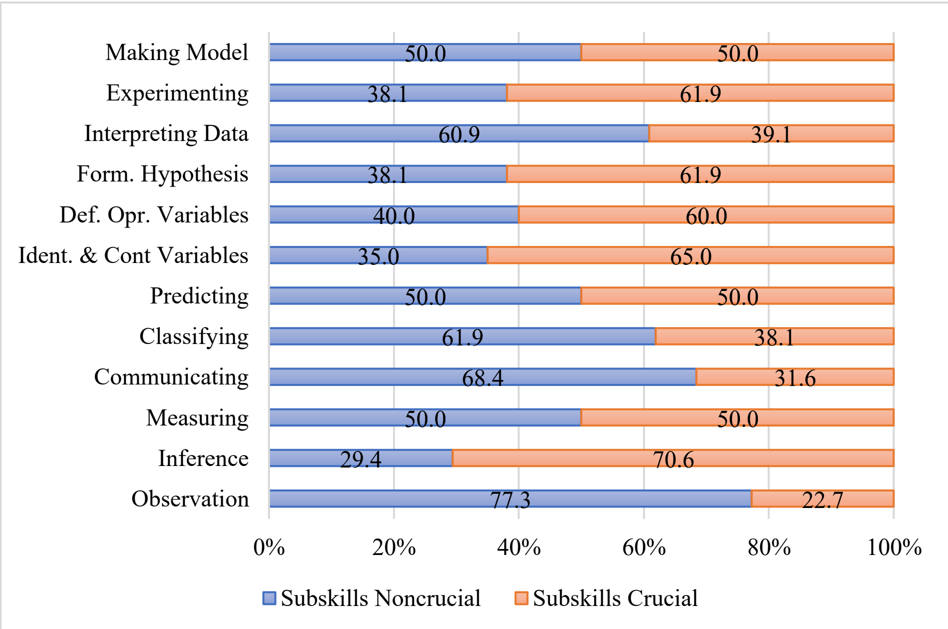


Figure 9. Percentage of each Subskills from 32 Included Studies in SPS

Lastly, experimenting skill was a crucial category in 61.9% of 21 studies (Gultepe & Kilic, 2015; Kamba et al., 2018; Ogan-Bekiroglu & Arslan, 2014). The studies concluded that sufficient physical experiences are needed for improving the science process skills. Duruk et al. (2017) argued that because these skills pose problems in terms of the science curriculum, the tricky parts of science handle the abilities that are influenced by the common structure of the science educational modules, which reflect course substance, lesson plans, learning action, and the outcome. Aydogdu (2017) stated that teachers should develop students' inference and measurement skills by requiring the active use of these skills in the classroom.

The participants in these studies seemed to have a problem in designing and conducting experiments. They also found it difficult to pose questions and formulate hypotheses. Various issues, such as students' prior knowledge, learning style, and learning process, the number of students in the class, and the time limitations, have to be considered for successful implementation (Jeenthong et al., 2013).

In summary, the crucial skills in SPS are mostly in the integrated domain, with inference and prediction skills being exceptions. Further, the studies revealed that the curriculum has an impact on the representation of SPS, and the curriculum change affected the representation of SPS.

Crucial Domains in Critical Thinking Skills

In this domain, 34 studies, including 15 articles on conference proceedings and 19 journal articles, which are listed in Table 6, were selected for review. The total sample from the selected studies comprised 3,608 participants who came from many levels, including primary, secondary, and university. Four studies were qualitative studies and 30 studies were quantitative, such as quasi-experiments and true experiments. Most of the selected studies were conducted in Asian countries, such as Malaysia, Indonesia, Thailand, Philippines, China, and South Korea; there were two studies each from the US, Turkey, Iran, and Oman.

Table 6. The Characteristics of 34 Included Studies in CTS

Author (Sample Size)	**Country**	**Institution**	**Design (Measurement Instrument)**	**Findings**
(Bagheri & Nowrozi, 2015)	Iran	Payame Noor University	• Comparative • Questionnaire	Evaluation skill and Induction skill were

(n = 60)			• Vocational university	the most averages among students; **Deduction, Explanation, and analysis skill**s were in the lowest average.
(Dilekli, 2017) (n = 225)	Turkey	Aksarary University	• Experimental • Questionnaire • Grade 5th to 8th	Interpretation, Evaluation, and Self-regulation skills emerged as the highest mean score; **Analysis, Inference, and Explanation skill**s emerged as the lowest mean score.
(Kumar, 2017) (n = 214)	Oman	Nizwa College of Technology	• Experimental • Questionnaire • College students	Assumption, deductions, and arguments skill were the highest mean score after study; **Interpretations skill and Inference skill** were the lowest mean score after study.
(Siriwat & Katwibun, 2017) (n = 47)	Thailand	Chiang Mai University	• Experimental • Questionnaire • Grade 11th, Secondary school	Explanation issues, and Evidence were the highest rated; **Influence of context and assumptions, Student's position and Conclusions and outcomes** were the lowest rated

(B. K. B. Putra & B. A. Prayitno, 2018) (n = 188)	Indonesia	Sebelas Maret University of Surakarta	• Quasi experimental • Questionnaire • Grade 11th, Secondary school	Interpretation skill, Analysis, and Explanation skill had the highest percentage; **Evaluation skill, Self-regulation and Concluding skill** had the lowest percentage.
(Usmeldi, Amini, & Trisna, 2017)	Indonesia	State University of Padang	• Experimental • Questionnaire • Secondary school	Analysis and Induction skill had the highest percentage; **Inference, Evaluation, and Deduction skill** had the lowest percentage.
(Ramos, Dolipas, & Villamor, 2013) (n = 393)	Philippines	Benguet State University	• Experimental • Questionnaire, Observation sheet • University school	**Analysis, comparison, inference and evaluation skills** were in the average level and below average level.
(Kong, 2014) (n = 107)	Hong Kong	The Hong Kong Institute of Education	• Experimental • Questionnaire • Grade 11th, Secondary school	Hypothesis identification, Induction, and Deduction skill had the highest mean score; **Evaluation skill and Explanation skill** had the lowest mean score.

(Duran & Dokme, 2016) (n = 90)	Turkey	Giresun University	• Experimental • Questionnaire • Grade 6th, Primary school	In this study, the result shows a significant difference between both groups in terms of the Measured analysis skill, Evaluation, Inference, Interpretation, Explanation, and Self-regulation.
(Zhou et al., 2013) (n = 119)	China	Normal University	• Quasi experimental • Questionnaire • Grade 12th, Secondary school	Analysis skill was statistically significant different in both groups, but **Evaluation skill and Inference skill** were not.
(Hairida, 2016)	Indonesia	University of Tanjungpura Pontianak	• Quasi experimental • Questionnaire • Grade 7th, Secondary school	Analysis skill and Explanation skills had shown the highest average score; **Interpretation skill, Inference, and Evaluation skill** had shown the lowest average.
(Shin, 1998) (n = 234)	Korea	Ewha Womans University	• Experimental • Questionnaire • Secondary school	Interpretation, Analysis, and Inference skill were statistically significant difference in both groups;

				Evaluation skill and Deduction skill were not significant in both groups.
(Asefi & Imani, 2018)	Iran	Tabriz Islamic Art University	• Quasi experimental • Questionnaire • University level	Inference skill and Evaluation skill got the highest mean score comparing to **Interpretation, Analysis and Explanation**.
(Stephenson, Miller, & Sadler-McKnight, 2019) (n = 159)	USA	Florida International University	• Quasi experimental • Questionnaire • University level	Inference skill, Evaluation, and Explanation skill got the highest mean score comparing to **Interpretation, Analysis**.
(Ratnadewi & Yunianti, 2019) (n = 4)	Indonesia	Muhammadiyah University of Surabaya	• Meta-analysis • Observation • University level	The result of the analysis indicated that 58.3% of the students got the Proficient Level achievement, spreading **from the critical skills of communication, analysis (interpretation) and synthesis**.
(Ow & Tan, 2017) (n = 20)	Malaysia	University of Malaya	• Experimental • Questionnaire	It was found to perform well in Classification, but they are weak in

			• Primary School	**analysing, evaluating, applying, and making inference** during problem-solving.
(Saputri, Sajidan, & Rinanti, 2018) (n = 294)	Indonesia	Sebelas Maret University	• Descriptive research • Questionnaire • Grade 12th, Secondary school	The critical thinking skill test resulted in the evaluation aspect score that reached the highest score, followed by Self-regulation skill and Analysis; On the other hand, **Interpretation skill, Inference and Explanation skill** got the lowest percentage of students' aspects
(Malik et al., 2018) (n = 60)	Indonesia	Indonesia University of Education	• Quasi experimental • Questionnaire • University level	Explanation, Analysis, and Evaluation skills were reported to be in the moderate improvement category, while Interpretation, Self-regulation, and Inference skills were reported to be in the low improvement category. (**Interpreting, Self-**

				regulation, and Inference).
(Sarasvati & Sriyati, 2018) (n = 40)	Indonesia	Indonesia University of Education	• Experimental • Questionnaire • Grade 8th, Secondary school	It can be concluded that junior high school students are still in **a position that their critical thinking skills are in enough category**.
(Setiawan, Malik, Suhandi, & Permatasari, 2017) (n = 60)	Indonesia	Indonesia University of Education	• Quasi experimental • Questionnaire • University level	Critical thinking skills aspect classified into two categories, namely medium category for Explain, Self-regulation and Analyse and low category for **Interpret, Inference, and Evaluate**.
(Hunaidah, Wasis, Prahani, & Mahdiannur, 2018) (n = 56)	Indonesia	State University of Surabaya	• Experimental • Questionnaire • University level	Positive results indicate an increase in collaborative critical thinking skills of physics education students, which is shown that all indicators of collaborative critical thinking skills are in high category.
(Irwanto, Saputro, Rohaeti, &	Indonesia	State University of Yogyakarta	• Quasi experimental	**Inference and Analysis skills** got the lowest mean score

Prodjosantoso, 2018) (n = 48)			• Questionnaire • University level	comparing to the other sub skills in critical thinking skills.
(Yulianti, Fauziah, & Hidayat, 2018) (n = 25)	Indonesia	State University of Malang	• Experimental • Questionnaire • Grade 11th, Secondary school	The high average scores are in Interpreting, Self-regulation, and Explanation skill; **Inference and Analysis skill** got the lowest average score.
(L. Smith et al., 2019) (n = 88)	USA	Wingate University School of Pharmacy	• Quasi experimental • Questionnaire • University level	The sub-scores where the students scored highest on the test were explanation and analysis. Meanwhile, **Interpretation, Inference and Evaluation** were the lowest in the test result.
(Hussein, Ow, Cheong, & Thong, 2019) (n = 127)	Malaysia	University of Malaya	• Quasi experimental • Questionnaire • Grade 5th, Primary school	Explanation skill emerged as the highest mean score, and **evaluation skill** emerged as the lowest mean score.
(Ramandha, Andayani, & Hadisaputra, 2018) (n = 75)	Indonesia	University of Mataram	• Quasi experimental • Questionnaire	Interpretation, Analysis, and Evaluation skill show the significance of the

			• Grade 10th, Secondary school	criteria for critical thinking skills; **Inference and Explanation skill** have lower critically.
(Amalia, Hartono, & Indaryanti, 2019) (n = 30)	Indonesia	Sriwijaya University	• Descriptive research • Trigonometric questions • Grade 10th, Secondary school	The highest average value is in the indicators of interpretation which has an excellent category. The lowest average value is in the indicator of **inference** which has the poor category.
(Fernandi, Firman, & Rusyati, 2018) (n = 110)	Indonesia	Indonesia University of Education	• Descriptive research • Questionnaire • Grade 9th, Secondary school	Analysis skill had the highest mean score comparing to **Interpreting and Inference skill**.
(Saprudin, Liliasari, Prihatmanto, & Setiawan, 2018) (n = 46)	Indonesia	Indonesia University of Education	• Survey research • Questionnaire • University level	Analysis skill is in the high category, meanwhile **Evaluation and Explanation** are in the low category.
(Cahyana, Fitriani, Rianti, & Fauziyah, 2018)	Indonesia	State University of Jakarta	• Qualitative research • Questionnaire	This noncrucial category shows that all students are able to meet the critical thinking ability

			• Grade 10th, Secondary school	indicator being studied by the researcher.
(Yerimadesi et al., 2018) (n = 67)	Indonesia	State University of Padang	• Quasi-experimental • Questionnaire • Grade 11th, Secondary school	All critical thinking indicators (Analysis, Inference, and Explanation skills) are in the "Very Good" category.
(Pamungkas, Aminah, & Nurosyid, 2019) (n = 99)	Indonesia	Sebelas Maret University	• Descriptive research • Questionnaire • Grade 11th, Secondary school	The result shows that the percentage achievement of students' critical thinking skills in solving the static fluid problem for indicators of **assessment, inference, and strategy** is still low, and the indicator of clarification is quite high.
(Shirazi & Heidari, 2019) (n = 499)	Iran	Shiraz University of Medical Sciences	• Experimental • Questionnaire • University level	The result showed that **Assessment, Analysis, and Inference skills** did not significantly increase during the time.
(Basri, Purwanto,	Indonesia	State University of Malang	• Descriptive research	The six critical thinking sub-skills

As’ari, & Sisworo, 2019) (n = 24)		• Interview • Grade 8th, Secondary school	identified, only the interpretation sub-skill was in the fair category, while the remaining five sub-skills of students' critical thinking were in a low category. **The evaluation, self-regulation, and inference sub-skills** were the sub-skills with the lowest percentage. It can be concluded that many students were less capable in those critical thinking sub-skills.

Six CTS sub-skills were included in this systematic review: Data interpretation, Analysis, Inference, Evaluation, Explanation, and Self-regulation. After conducting data extraction, it was found that three sub-skills were identified as being crucial in science education, with the percentage shown in Figure 10.

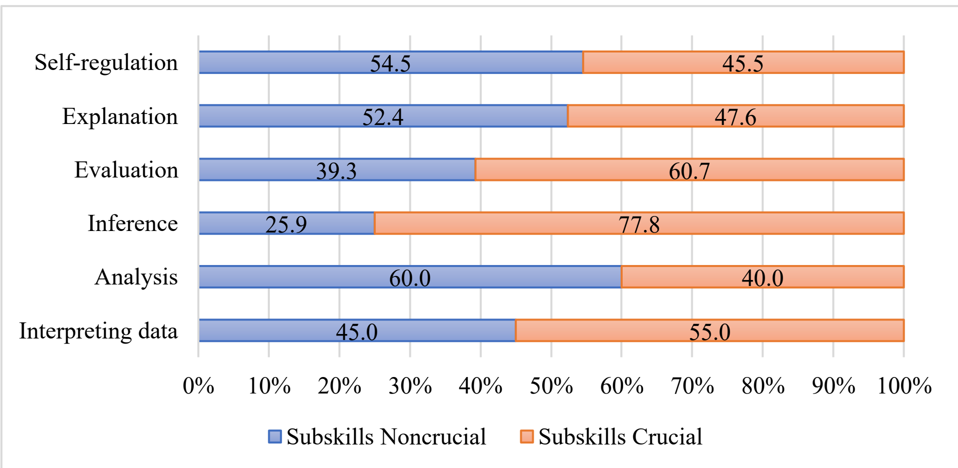


Figure 10. Percentage of each Subskills from 34 Included Studies in CTS

Interpreting data (55.0% of 20 studies) was found to be one of the three crucial skills (Asefi & Imani, 2018; Kumar, 2017; Malik et al., 2018; Saputri et al., 2018; Stephenson et al., 2019). The second skill was inference, with 77.8% of 27 studies revealing a low mean score (Dilekli, 2017; Fernandi et al., 2018; Irwanto et al., 2018; Ow & Tan, 2017; Ramos et al., 2013; Shirazi & Heidari, 2019; L. Smith et al., 2019; Yulianti et al., 2018). The last was evaluation skill, with 60.7% of 28 studies confirming the low average score (Hussein et al., 2019; Kong, 2014; Ow & Tan, 2017; Ramos et al., 2013; Shirazi & Heidari, 2019; L. Smith et al., 2019; Zhou et al., 2013). Most of these studies compared the average score of each sub-skill through different methods, such as inquiry-based learning, formal logic course, peer-led team learning, problem-based learning, and knowledge learning in the digital classroom.

Crucial Domains in Reasoning Skills

The reasoning skills category consists of six sub-skills: Conservation law, proportional reasoning, control of variable, probabilistic reasoning, correlational reasoning, and hypothetical deductive reasoning. These skills were measured in 12 studies (three conference proceedings and nine journal articles) with a total sample of 31,028, which can be seen in Table 7.

Table 7. The Characteristics of 12 Included Studies in RS

Author (Sample Size)	**Country**	**Institution**	**Design (Measurement Instrument)**	**Findings**
(Remigio et al., 2014) (n = 93)	Philippines	Ateneo de Manila University	• Quasi-experimental • Questionnaire • Grade 10_{th}, Secondary level	Conservation of weight and volume, and Probabilistic reasoning skill got the highest mean score; **Proportional reasoning, Control of variable, and Correlational reasoning skill** got the lowest mean score.

(Muslim, Suhandi, & Nugraha, 2017) (n = 104)	Indonesia	Indonesia University of Education	• Research and Design • Questionnaire • Secondary school	Only Hypothetical deductive reasoning got the highest average score; **Conservation, Control of variable, Probabilistic reasoning, and Correlational reasoning** got the lowest average score.
(Mendoza et al., 2018) (n = 35)	Columbia	Manuela Beltran University	• Quasi-experimental • Questionnaire • University level	In PBL, Proportional variable skill, Control of variable, and Probabilistic reasoning skill had shown improvement of correct answer percentage; **Conservation skill, Correlational reasoning, and Hypothetical-deductive reasoning** had decreased of correct answer percentage.
(Mendoza et al., 2018) (n = 35)	Columbia	Manuela Beltran University	• Quasi-experimental • Questionnaire • University level	In CL, all seven reasoning skills had decreased of correct answer percentage.

(Piraksa et al., 2014) (n = 400)	Thailand	Khon Kaen University	• Experimental • Questionnaire • Grade 11th, Secondary school	Conservation mass and volume skill and Correlational reasoning skill showed the highest mean score; **Proportional reasoning skills, Control of variables, Probabilistic reasoning, and Hypothetical-deductive reasoning skill** show the lowest mean score.
(Yuksel, 2019) (n = 31)	Turkey	Gazi University	• Experimental • Questionnaire • University level	Proportional reasoning, Control of variables, and Probabilistic reasoning skill got the highest means score; **Conservation laws, Correlational reasoning, and Hypothetical deductive reasoning** got the lowest mean score.
(Stammen, Malone, & Irving, 2018a) (n = 32)	USA	The Ohio State University	• Experimental • Questionnaire • University level	Conservation Mass and volume, Probabilistic reasoning, and Control of variables skill got the highest mean percentage score;

				Proportional reasoning skills, Correlational reasoning, and Hypothetical deductive reasoning got the lowest mean percentage score.
(Ross & Cousins, 2006) (n = 12)	Canada	Ontario Institute for Studies in Edu	• Experimental • Questionnaire • Grade 9th to 10th, Secondary School	The impact of the program was mediated by teacher commitment to improving students' correlational reasoning skills and by teacher efficacy. The program was less successful in developing students' ability to **conclude correlational data**.
(Jensen, Neeley, Hatch, & Piorczynski, 2017) (n = 30,000)	USA	Brigham Young University	• Experimental • Questionnaire • University level	Conservation of mass and probabilistic reasoning skill got the highest score of the total mean score; **Proportional reasoning, Control of variable, Correlational reasoning, and Hypothetical deductive reasoning** got the lowest score of the total mean score.

(Wulandari & Shofiyah, 2018) (n = 18)	Indonesia	University of Muhammadiyah Sidoarjo	• Experimental • Questionnaire • University level	Proportional reasoning and Control of variables got the highest student's mastery; **Conservation laws, Probabilistic reasoning, and Correlational reasoning** got the lowest student's mastery.
(Susilawati & Anam, 2017) (n = 208)	Indonesia	State University of Semarang	• Pre-experimental • Questionnaire • Grade 11th, Secondary school	Hypothetical deductive reasoning got the highest mean score with high increment; **Correlational reasoning and Probabilistic reasoning skill** got the lowest mean score.
(Rosdiana, Siahaan, & Rahman, 2019) (n = 60)	Indonesia	Indonesia University of Education	• Observation • Questionnaire • Grade 9th, Secondary school	Combinatorial reasoning, Correlational reasoning, and Controlling variables got a high percentage of correct answer; **Conservation reasoning, Proportional reasoning, and Probabilistic reasoning** got the

	lowest percentage of the correct answer.

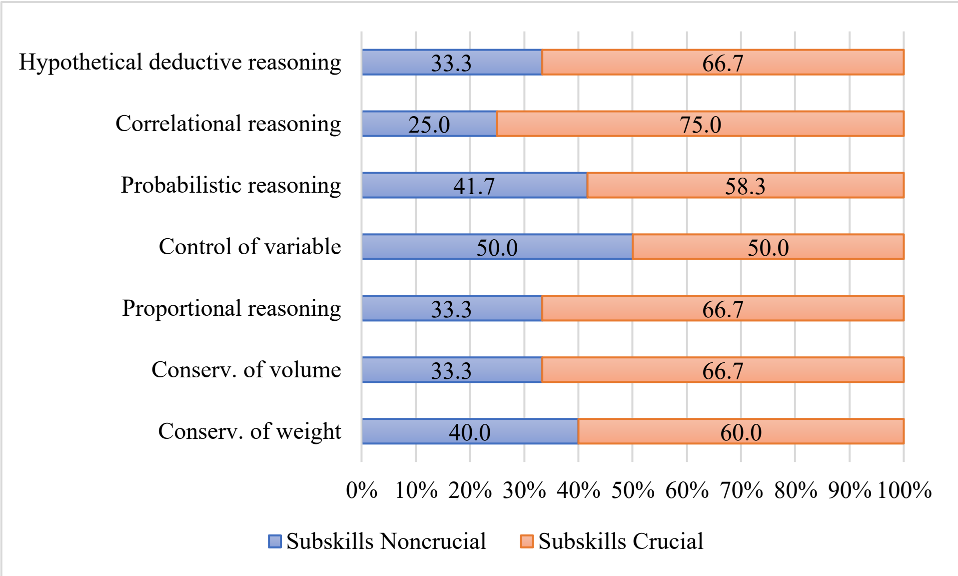


Figure 11. Percentage of each Subskills from 12 Included Studies in RS

As portrayed in Figure 11, all sub-skills in reasoning were in the crucial category based on the studies analyzed. None of the skills accounted for more than 50% in the non-crucial category. Conservation of weight and volume skills were identified as crucial in 60.0% of 10 studies and 66.7% of 9 studies, respectively. Proportional reasoning was viewed as crucial in 66.7% of 9 studies, control of variable in 50.0% of 10 studies, probabilistic reasoning in 58.3% of 12 studies, correlational reasoning in 75% of 12 studies, and hypothetical deductive reasoning in 66.7% of 9 studies (Jensen et al., 2017; Piraksa et al., 2014; Remigio et al., 2014; Ross & Cousins, 2006; Susilawati & Anam, 2017; Wulandari & Shofiyah, 2018; Yuksel, 2019).

In total, eight studies revealed the range of mean scores in order to identify the category of sub-skills with and without intervention. Six of the eight studies used learning methods such as inquiry-based learning, problem-based learning, 5E learning model, and analogy-enhanced instruction. Mendoza et al. (2018), Muslim et al. (2017), and Rosdiana et al. (2019) showed the percentage of correct answers. Stammen et al. (2018a) called for more studies to extrapolate the findings of RS in science education.

The Relationships among Three Thinking Skills

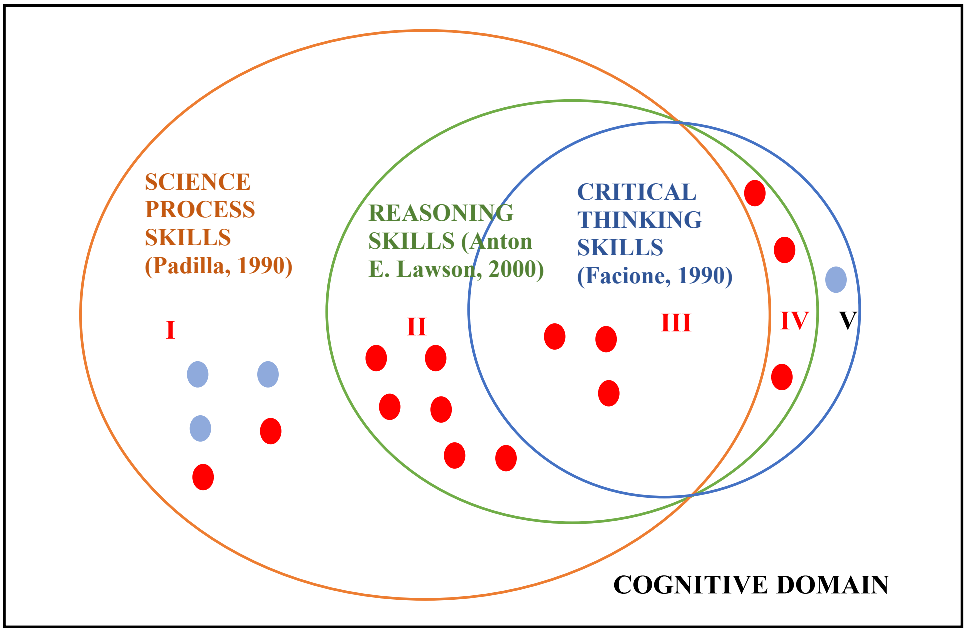


Figure 12. Conceptual Framework of Relationships among Thinking Skills

The systematic literature search yielded information on the relationships between the thinking skills in science education, which are depicted in Figure 12, an adaptation of Figure 3. This figure shows the location of the crucial thinking skills, with the blue dots indicating the sub-skills included in the non-crucial category and the red dots indicating sub-skills included in the crucial category. It was found that the crucial thinking skills exist in groups I, II, III, and IV. As explained by the researcher in the literature review, Group I consists of sub-skills from SPS. The results of the systematic review showed that only measurement and operational definition are crucial skills, while the other sub-skills are included in the non-crucial category. Further, Group II pictures the relationships between SPS and RS. The findings showed that identification and control of variables (HD2), prediction (HD3), hypothesis formulation (HD5), experimental design/ model making (HD5), and experiment execution (HD5) are crucial skills. These skills also covered most of the sub-skills of RS and are called integrated science process skills.

Meanwhile, Group III pictures the relationships between SPS, RS, and CTS comprising all the crucial skills, including interpretation of data (HD1), inference (HD4), and analysis skills (HD4). Lastly, Group IV pictures the relationships between RS and CTS comprising simple explanation (conservation reasoning/EI), explanation (HD5), and evaluation (HD5).

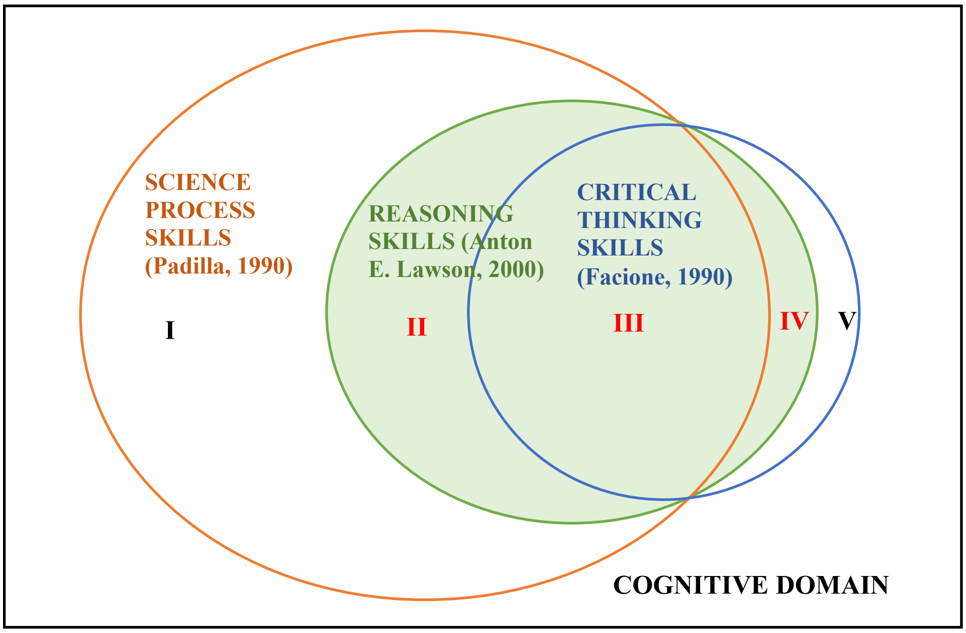


Figure 13. The most Crucial Area of Thinking Skills

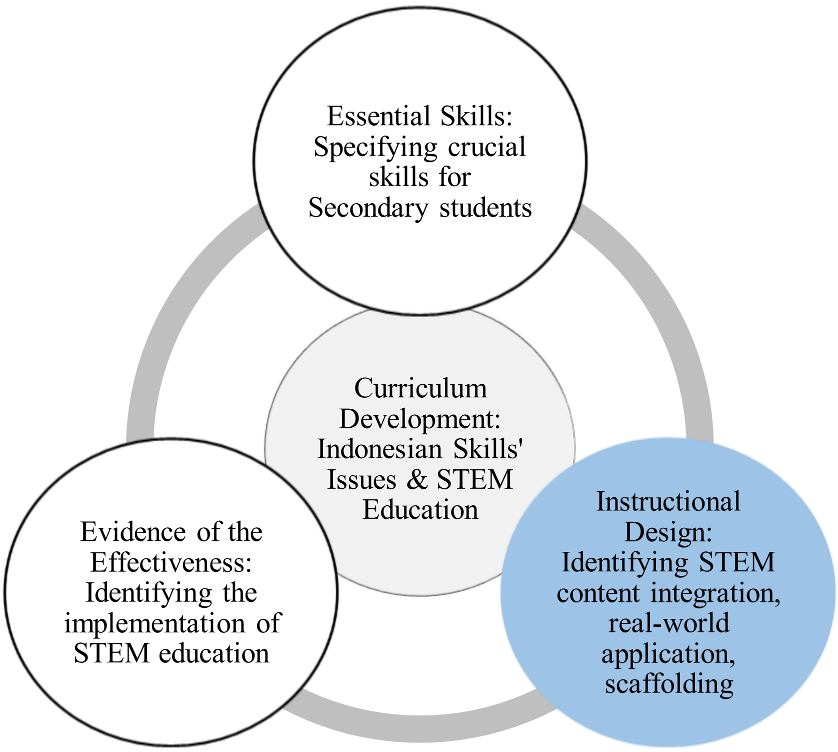
In conclusion, most of the crucial thinking skills existed in the reasoning skills group that covered mostly integrated science process skills and the three sub-skills of critical thinking skills, which are represented by the green-shaded area in Figure 13.

CHAPTER 5 INSTRUCTIONAL DESIGN OF STEM EDUCATION IN INDONESIA

The capacity to collaborate and think creatively and innovatively while teaching is a minimal requirement in STEM education (Beswick & Fraser, 2019; Eckman et al., 2016). Teachers' understanding of STEM education should be established across domains through practice (Kelley & Knowles, 2016). Gurol (2004) and Tasdemir (2003) in Konokman, et al., (2017) confirmed that no matter how good a new educational system is, it will not achieve its objectives unless teachers as implementers fulfill their tasks efficiently.

Teachers are seen not only as the active curriculum implementers, but also as primary players in terms of providing feedback on the current curriculum and recommendations to improve it. Teachers are expected to implement the curriculum by mastering the principles of teaching, significance, contents, learning-teaching approaches, educational technologies, and evaluation processes. Thus, in this study, teachers are assumed to contribute to the curriculum development process in terms of STEM content integration, real-world application, and scaffolding of STEM education in Indonesia based on their practical experience, knowledge of the curriculum, and feedback about the implemented curriculum.

Methodology of the Second Stage



The second stage aimed to shed light on the second essential area, i.e. instructional design, based on the theoretical framework involving three significant elements: STEM content integration, real-world application, and scaffolding. Before the data collection process, a STEM professional development (PD) program was conducted to introduce STEM education to all participants in this study. The details are explained below as the precondition of data collection.

Data Sources

The focus of this qualitative study was on teachers' experiences, opinions, knowledge, and beliefs. Previous studies have suggested measuring these aspects through preconditions such as professional development programs (Calisici & Sumen, 2018; El-Deghaidy & Mansour, 2015; Erdogan & Ciftci, 2017; Hammack & Ivey, 2016).

Therefore, a STEM professional development program complemented this study and aimed to provide initial information on building a successful, sustainable, and integrative STEM education program and teachers' role in achieving this objective. The four-day training program was conducted with the support of the MGMP Fisika-Physics Teachers Association.

The STEM professional development program emphasized three things. First, it stressed teachers' understanding of the concept of integration and how to teach S-T-E-M. Second, teachers needed to have a background in one or more disciplines, content and process knowledge, and an understanding of the interdisciplinary approach developed from the four main subjects. Lastly, the STEM professional development program aimed to be different from preparation programs for science, technology, or mathematics teachers because it represents the integration of disciplines (Pimthong & Williams, 2018). There were four sessions: introduction session, simple experiments session, advanced experiments session, and interview session. The content of the program covered the concepts of Science, Technology, Engineering, and Mathematics and STEM implementation.

Following the STEM professional development program, a semi-structured interview was conducted to collect data for this study. This activity involved having a natural conservation with participants, with the researcher asking questions, listening to their answers, taking notes for each participant to script valuable information, and recording the conservation to determine the impact of the development program. In this study, the researcher asked six questions:

1. Have you ever heard of STEM education before the professional development program?
2. How was your pre-service teacher training like? Was STEM education part of the training?

3. How do you think STEM education compares with conventional instruction?
4. Which subject is the most difficult in STEM education?
5. What do you think about the impact of STEM education on students' achievements (knowledge and skills)?
6. What do you think are the challenges that STEM education could face in physics class?

The first and second questions aimed to determine the extent of STEM content integration in Indonesia, the third question sought to discover the real-world application, and the fourth, fifth, and sixth questions aimed to learn about the scaffolding of STEM education in Indonesia as shown in Table 8.

Table 8. Essential Areas and List of the Questions during Interview

Essential Area	Questions
STEM CONTENT INTEGRATION	1. Have you ever heard of STEM education before the professional development program? 2. How was your pre-service teacher training like? Was STEM education part of the training?
REAL-WORLD APPLICATION	3. How do you think STEM education compares with traditional instruction?
SCAFFOLDING	4. Which subject (science, technology, engineering, or math) is the most difficult in STEM education? 5. What do you think about the impact of STEM education on students' achievements (knowledge and skills)? 6. What are the challenges that you think STEM education could face in science class?

Participants

This study employed phenomenological research to understand teachers' perceptions and perspectives related to particular experiences and other situations (Leedy & Ormrod, 2015). In this case, the researcher intended to gain teachers' perceptions on STEM content integration, real-world application, and scaffolding based on their understanding and experiences. This study conducted purposive sampling from 38 sub-districts in Pangkep Regency, which is at a distance of about 49 km from Makassar, the capital city of South Sulawesi, Indonesia, to ensure diversity and obtain comprehensive data. The participants were divided into two groups: new teachers (0 to 10 years of teaching experience) and experienced teachers (more than 10 years of experience). Thus, five new teachers and nine experienced teachers were interviewed. All participants had an academic degree in science and taught physics at the senior high school level. To ensure anonymity, the names of all participants have been coded.

Data Analysis

The qualitative data analysis utilized an inductive and traditional approach that involved several steps (The details are attached in the Appendix).

1. The first step was organizing the data, which involved four aspects. First, the participants' answers to each question were tabulated and the data was transcribed with a word processor. The researcher then utilized Microsoft Word to translate, clean, and label the data.

Sample / Question	1	2	3	4	5	6	7	8	9	10	11	12	13	14

2. The second step was identifying the framework, or the coding plan, which was guided by the research question.
3. The third was sorting the data into the framework by coding data and modifying the framework.
4. The fourth was using the framework for descriptive analysis by arranging the responses in categories; in this study, the researcher divided the responses into two categories based on teachers' years of teaching experience.
5. The last step was completing the second order analysis to identify patterns in the data that can help answer the research questions.

Result

The results cover the three areas of STEM content integration, real-world application, and scaffolding.

STEM Content Integration

STEM content is imparted through an integrated, interdisciplinary teaching approach in which students have multiple opportunities to apply STEM skills and knowledge in the context of STEM activities, problems, and/or practices. This study examined the alignment of STEM content with relevant instructional frameworks from teachers' perspectives.

To the first question, "*Have you ever heard of STEM education before the professional development program?*" the responses were similar in both categories of teachers as can be seen in Table 9.

Table 9. Science Teachers' Knowledge Joining the PD Program

Category	**Participant (N: 14)**	
	Exp	**New**
I came to know about STEM education only after attending this PD program	4	2
I have previously heard about STEM education, and this is the second time or more	5	3

Nearly half of the participants did not know about STEM education before the PD program, while the rest had learnt about STEM education in the past two years from various sources. Currently, STEM education has been adopted by the government and delivered by supervisors at meetings of local subject-based teacher communities called Musyawarah Guru Mata Pelajaran (MGMP).

> "*Recently, our supervisors have been encouraging us to learn more about STEM education. They plan to talk about STEM education in each meeting and are conducting a one-day seminar to raise awareness about STEM education, and the seminar will be conducted tomorrow*."

The second question was about teachers' experiences during their pre-service training.

Table 10. Teachers' Experiences during Pre-service Training

Category	Participant (N: 14)	
	Exp	New
I never heard about STEM education during my pre-service training and have never conducted STEM education	6	0
I never heard about STEM education during my pre-service training, but have conducted STEM education	3	5

According to Table 10, eight teachers admitted that they conduct STEM education although they were not aware of the concept of STEM education. Interdisciplinary teaching depended on teachers' interest and motivation and mostly involved a combination of two or three subjects, and was not as fully integrated as STEM. This is due to lack of guidance or direction from the community and government.

All teachers revealed based on their experience that explanations about STEM education have not existed at the university level in Indonesia for the last 30 years. Moreover, they tended to conduct interdisciplinary teaching by combining two or three STEM subjects, and not all of them as required in fully integrated STEM education. This finding also showed that new teachers pay more attention to and have greater interest in STEM education than experienced teachers based on the frequency of the implementation.

> *"I tend to conduct STEM education in my classes, but I did not know that it was called STEM education. It is not fully integrated STEM, because I rarely combine four disciplines; sometimes I only combine two or three disciplines, and try to build the connection between the learning process and students' daily life experiences.*
>
> *"For example, in one learning process, I guided the students to build a rocket which involves science (fluid, force), technology (the final result of the rocket), engineering (the process of designing the rocket), and math (the size of the rocket)."*

Real-world Application

Content is embedded in scenarios related to problems or challenges that students are likely to encounter outside of school at some time in their lives. In STEM education, the relationship between instructional content and real-world application is made explicit to students. Therefore, this aspect was determined through teachers' perceptions.

The third question asked teachers how they compare STEM education with traditional instruction. It emerged that there was no difference between experienced and new teachers' perceptions. All 14 teachers agreed that STEM education is more challenging compared to traditional instruction. The teachers mentioned three characteristics, i.e., STEM education is the most updated learning process and related to real-world challenges and activities, STEM education is interesting, and STEM education provides hands-on activities. They believed that STEM education could give students a better chance to explore real-life challenges and help align their interests in class with their activities outside.

> "*Today's students are different from those 10 years ago. Students are more active and dynamic, and thus are not satisfied by traditional learning. STEM education provides opportunities to pursue activities that match students' interests, helps them apply their knowledge to real-world activities, and prepares them for workplace demands. In addition, even though STEM education is appropriate to the physics learning process, all facilitators in education have to realize the need for effort*."

Scaffolding in STEM Education

Materials in STEM education provide clear guidance and support to move students progressively toward deeper understanding and greater independence in the learning process. This study examined the state of scaffolding in STEM education in Indonesia based on the teachers' perspectives.

The fourth question revealed the toughest of the four disciplines in STEM education. Based on the interview results, which are shown in Table 11, engineering emerged as the most challenging discipline to be implemented, followed by mathematics, technology, and science. Most teachers believed that the complexity of engineering makes it difficult to be implemented at the primary and secondary level.

Table 11. The Most Challenging Field among STEM Disciplines

Category	Participant (N: 14)	
	Exp	New
Engineering	4	3

Mathematics	3	1
Technology	2	1

In their responses to the fifth question, teachers confirmed the huge advantages of STEM education in terms of improving students' quality of knowledge and skills. The government and other facilitators in education, including teachers, must focus on supporting the capabilities to implement STEM education. Interestingly, one of the new teachers noted that school goals and the national examination goals are not in line with the goals of STEM education. These conditions have driven teachers to improvise the learning process.

> "*In my school, most of the teachers, including me, find it difficult to change from traditional instruction to STEM education. It is not because STEM education cannot help us improve students' capabilities, but due to the fact that our school goals and our national examination targets do not correspond with the STEM system. STEM education emphasizes the learning process, so students can gain a deep understanding of the concepts and problems, and develop an interest in science, technology, engineering, and mathematics. On the other hand, school goals underscore theoretical knowledge, not practical application. Hence, there is a gap between the expected learning process and the expected achievements of students. It leaves teachers with no choice, except finding a way to maximize students' answering capabilities in the national examination*."

> "*In developing countries such as Indonesia, STEM education will be more appropriate in urban than rural areas. It is similar to what we have done in the revised curriculum; it needs step by step implementation for long-term benefits*."

Teachers pointed out some challenges and limitations, which are listed below.

1. Time constraints in and after class;
2. Lack of awareness among teachers about the effective teaching method;
3. Lack of technological support;
4. Content of the national curriculum; and
5. Main goal of the national examination in Indonesia.

These are not all wholly new, but they are particularly significant for the implementation of STEM education in developing countries especially Indonesia. Time constraints were one of the most common challenges cited by both experienced and new teachers. Time was limited for not only classes, but also preparation. Teachers only had three 45-minute sessions for grade X and four 45-minute sessions for grade XI and XII in one week. Teachers felt that this time will not be enough for implementation.

> *"We have to complete a lot of work, excluding teaching arrangements. STEM education requires a lot of understanding and preparation, so many teachers choose traditional instruction."*

The implementation of the new curriculum depends on teachers' attention. Some teachers believed that implementing a new system was useless. This was the case especially when there is a lack of supporting facilities, for instance, technology.

The other challenges were related to the content of the national curriculum and the goals of the national exam. In Indonesia, there is no specific curriculum that manages STEM education. Recently, some teachers have started utilizing STEM. However, implementation was limited in terms of teachers' creativity in integrating one discipline with the other disciplines, and STEM integration was inadequate as most of the teachers only combined two or three disciplines. Furthermore, teachers also pointed out that the national exam focused exclusively on knowledge, not skills. The government needs to take into account these challenges before implementing STEM education nationwide.

Discussion and Conclusions

The second stage aimed to shed light on the second essential area of STEM education, i.e., the instructional design of STEM education in Indonesia, based on teachers' perceptions. It covered three significant aspects: STEM content integration, real-world application, and scaffolding in STEM education.

The first finding was that STEM education has not existed at the university level for the last 30 years, and some of teachers came to know about STEM education only after attending the professional development program. However, this is not surprising given that the term STEM education has been gaining recognition in the country only in the past two years. Currently, the government has adopted STEM, which is delivered by supervisors through MGMP meetings.

In addition, teachers have conducted STEM education without being aware that they are actually following STEM. Yet, implementation is still limited and depends on teachers' interest and motivation due to lack of guidance or direction. The teachers acknowledged the huge advantages of STEM education in improving students' quality of knowledge and skills and also mentioned three significant characteristics, i.e. "STEM is interesting"; "STEM provides hands-on activities" and; "STEM is the most updated learning process." They believed that STEM education could give students a better chance to explore real-life challenges and help align their interests in class with their activities outside.

Theoretically, STEM education has been around for decades, and no one realized its importance until 1957 when teachers in the US broadly agreed on the value of STEM education in ensuring America's edge in the global economy (White, 2014). STEM education has existed since a long time, but it has only been recently promoted in Indonesia with limited information sources. One previous study supported this study's finding that the concept of STEM education in Indonesia has become popular in recent years, especially at the higher education level. It is consistently developing in the education sector, supported by researchers and academicians (Suprapto, 2016).

The second finding was that STEM education is more appropriate for present day students given the relationship between the instructional design of STEM education and real-world application. Nowadays, students are expecting real-world connections to what they are learning, which they potentially get through STEM education, or else they may completely disengage (El-Deghaidy & Mansour, 2015; Havice et al., 2018). The emergence of STEM in the public K-12 education system has provided opportunities for students at all levels to master skills necessary for 21st-century learning using a variety of activity-based learning models. STEM education provides students an accelerated path to gaining in-depth knowledge (Meyrick, 2011). It also involves inquiry-based, problem-based, and project-based learning. It allows students to explore real-world problems simultaneously while developing cross-curriculum skills, such as reasoning skills, creativity, collaboration, problem-solving, and research skills. It is useful for selecting careers in science. These issues are part of the priority plan for the Indonesian curriculum in the Ministry of Education and Culture's 2015-2019 strategic plan (MoEC, 2015).

Nowadays, students are expecting real-world connections to what they are learning, or else they may completely disengage (El-Deghaidy & Mansour, 2015; Havice et al., 2018) that they potentially find through STEM education.

The last finding was that engineering is the most challenging discipline among the STEM subjects, followed by mathematics, technology, and science. Science was possibly viewed as the easiest subject because this study interviewed physics teachers who handle science almost every day in their life. Teachers were unfamiliar with the work of engineers and have little experience in teaching engineering design (Hammack & Ivey, 2016; K. L. Smith, Rayfield, & McKim, 2015). All educators need to realize that engineering is the situated context and the platform for STEM education.

According to previous research, engineering was seen as the most challenging field because of 1) the lack of a widely accepted vision; 2) lack of formal engineering education programs; 3) lack of informal support for engineering education; 4) rough treatment of key engineering ideas; 5) gender gaps; and 6) technical difficulties.

The current engineering education curriculum has been designed without the strategic vision of what should be covered in K-12 engineering. Indeed, the “qualifications” for engineering educators at the K-12 level have not even been described, and most teachers do not have engineering degrees. It is generally true that engineering school graduates are trained to work as professionals in the industry and are not equipped or certified to teach in K-12 schools. Usually, there is an intergenerational gap in education, specifically in engineering education (Ayyash & Black, 2014). This issue needs to be addressed for effective implementation of STEM education at the secondary education level around the world.

In addition, teachers also pointed to some challenges, including time constraints, lack of teacher awareness, and lack of technological support, which were also mentioned in previous research (Kanadh, 2019; Siew, Amir, & Chong, 2015). These issues were identified as the most common challenges to STEM education (Shernoff et al., 2017). In addition, teachers also noted the mismatch between Indonesian curriculum and STEM education. Balancing the national examination goals with STEM education goals depends on teachers’ familiarity with STEM education. Previous studies have suggested that teachers be given training and easily-accessible and recycled materials on STEM, and also be required to participate in group activities and do projects related to STEM education outside of school hours (Hattie & Yates, 2013; Higgins, Xiao, & Katsipataki, 2012; Kanadh, 2019; Siew et al., 2015).

The last challenge was the gap between the Indonesian curriculum and STEM education. There were two points that teachers mentioned. The first was the content for integrated STEM and the second was the national examination target. The learning process in STEM education should emphasize not only knowledge but also skills, especially 21st-century expertise to enable students to benefit in the future workplace (Burrows & Slater, 2015). The national examination target in Indonesia places more emphasis on knowledge, which may force teachers to avoid skills development in the learning process.

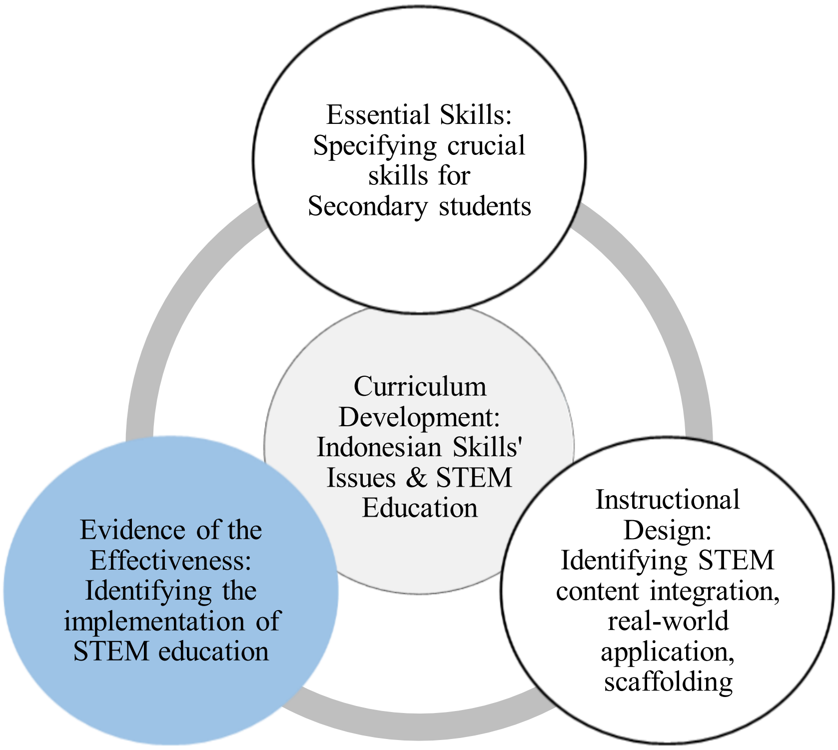
Previous research has clarified two approaches to incorporate STEM education into the curriculum: correlated curriculum and broad fields' curriculum. McNeil (1990) in Herschbach (2011) said the correlated curriculum pattern tends to be more popular because in this option, each subject retains its identity and may be offered as a separate course. With the broad fields' curriculum, a cluster of related but different subjects is organized into a single area of study (Herschbach, 2011).

In the Indonesian case, the correlated curriculum could be used to implement STEM education, which requires well-planned coordination between the different stand-alone subjects. Thus, to address these challenges, teachers will have to be more prepared, including by analyzing the contents and making connections between the subjects. More preparations are also needed from other participants in the education sector, including government and administrators, who should support teachers by providing facilities to create a well-implemented STEM education system in Indonesia.

This study has important implications for the implementation of STEM education in developing countries, including Indonesia, even though further research is needed. The researcher recommends document observation as an additional data source in future research to confirm the findings of this study. In addition, it is important to create effective STEM professional development programs in both pre-service and in-service training for Indonesian teachers to help them build an understanding of STEM education. Lastly, students' reaction to STEM education also needs to be determined to complement the findings of this study.

CHAPTER 6 THE EFFECTIVENESS OF STEM EDUCATION IN INDONESIA

Methodology of the Third Stage



The third stage utilized the findings from the first and second stages to determine the effect of STEM education on the crucial thinking skills or “reasoning skills” in Indonesia, which was the third essential area in the STEM framework. The choice of reasoning skills was supported by Indonesia’s 2013 curriculum reform, which required science teachers to integrate thinking skills, including reasoning skills with content learning objectives, as part of their general teaching and learning activities (MoEC, 2016). This stage utilized a quasi-experimental design involving an experimental group and a traditional group.

Teaching Intervention

The details of the competencies in physics education in Indonesia are shown in Table 12. The competencies range from developing curiosity to formulating problems, analyzing concepts, and modifying or designing simple projects. Each competency is linked to the scope of the content decided by the Ministry of Education.

Table 12. The Scope of the Competency

Competency Level	Competency	The Scope of Content
Senior high school	• Developing curiosity, honesty, responsibility, logical, critical, analytical, and creative through learning physics • Formulating problems related to physical phenomena, formulate hypotheses, designing and carrying out experiments, taking meticulous measurements, recording and presenting results in tables and graphs, conclude, and report results verbally and in writing • Analyzing the concepts, principles, and laws of mechanics, fluids, thermodynamics, waves, and optics and applying metacognition in explaining natural phenomena and solving the problems of life • Modifying or designing simple projects related to the application of the concepts of mechanics, fluids, thermodynamics, waves, or optics	• The nature of physics and measurement of physical quantities • Kinematics • Dynamics • Hooke's law of elasticity • **Fluid statics and dynamics** • Temperature, heat, symptoms of global warming (causes, effects, and solution) • Wave equation • Light and optical devices • Sound waves

In this stage, the scope of the content covered only “fluid statics and dynamics,” which was delivered through six meetings, including one pre- and one post-test session and four meetings each for the STEM group and traditional group as shown in Figure 14.

a. STEM group *b. Traditional group*

Figure 14. Meeting Details

Further, all participants were divided into two groups: the STEM group and the traditional group. The STEM group received STEM education with inquiry as the center of authentic STEM education to expand the science learning process by connecting it with technology, engineering, and mathematics (Blue, 2014; Warner & Myers, 2012).

STEM education allows teachers to address specific elements of inquiry (Blue, 2014). Thus, the researcher provided the basic competency and list of indicators as can be seen in Table 13 and created the STEM education practices for each meeting, which are shown in Table 14. STEM education differs from traditional science instruction in that it focuses on inquiry-based instruction, emphasizes the natural connection between science, technology, engineering, and mathematics, and uses application-oriented approaches involving experiments that not only have a positive impact on the crucial thinking skills of students, but also create and increase students' interest in science, technology, engineering, and mathematics fields and careers. There were four general inquiry phases including inquiry invitation, guided inquiry, open inquiry, and inquiry resolution. The first phase involved simply taking up a technological example in science teaching, with the selected example related to the daily life experiences of students. In the second and third phases, students conducted full experiments on the topic/example related to their daily life experience, which the teacher had mentioned in the first phase. The fourth and final phase was related to how the students completed their experiments and discussed the results. Students in the STEM group were divided into several small groups, with each group consisting of 5-6 students, while the teacher served as a facilitator to help the students in problem-solving during the learning process.

LESSON PLAN

Subject : Physics

Class/Semester : XI/I

Topic : Fluid Statics

Time : 4 meetings x 4 learning hours @45 Minutes each

Table 13. Basic Competency and Indicators

Basic Competency	*Indicator*
Implementation of fluid statics laws in daily life	• *Identifying how to implement fluid static laws in daily life* • *Concluding the concept of hydrostatic pressure*
Planning and doing experiment to utilize the nature of fluid statics	• *Planning an experiment that utilizes the nature of fluid statics* • *Conducting the experiment* • *Creating report for the experiment results* • *Presenting the results of implementation of fluid statics' laws*

Table 14. STEM Education Process using Inquiry-based Instruction

Meeting	Teacher Activities	Content	Student Activities
1st	• Teacher conduct orientation, greeting, checking student's attendance • Teacher introduce the topic ***1. Fluid*** *is a substance that continually deforms (flow under an applied shear stress, or external force* ***2. Hydraulic system*** *is a descriptive term for a system operated or moved by a fluid* ***3. Pressure*** *is a physical force exerted on an object* ***4. Hydrostatic pressure*** *is the pressure that is exerted by a fluid at equilibrium at a given point within the fluid, due to the force of gravity* ***5. Pascal Law:*** *The pressure applied to any part of the enclosed liquid will be transmitted equally in*	**INQUIRY INVITATION** *Introducing the science content through: Definition of the concept of fluid, hydraulic system, hydrostatic pressure, Pascal law*	• Students respond the teacher for attendance • Students listen to the teacher's explanations and searching information on the book and web about the topic.

	all directions through the liquid	• *The relationship between the topic and the real-life application* *(The application of hydraulic system, for example in a construction machine)*  *(Building process are needed, such as; the body, the arms, the forearm and the gripper of the construction machine)*	
		• *Raising inquiry question and brainstorming on function of hydraulic law theory.*	• Students start thinking, discussing, and brainstorming solutions
	"What is the function of hydraulic law theory?"		*"to make the construction machines work"* *"Yes"*

"Have you ever seen the construction machines before?" *"Where do you usually see the construction machines?"* *"How do they work on the construction process?"* *"How do they work?"* *"How do you think about the relationship between the body of construction machines and the hydraulic system?* *"HOW?"*	*"Near my home, on TV, and so on"* *"The construction machines were used to move a big/heavy staff like stone, soil, iron and so on.* *"The body of the machine will get closer to the stuff, the arm and the forearm will go up and down, and the gripper will hold/take the stuff"* *"The machine uses the hydrostatic pressure to move the body of construction machine"* • In this phase, the learning process just started, some of the students showed enthusiasm and some of the students also seemed ignorance.

		GUIDED INQUIRY	
		1st Investigation	
	• Teacher help the students on identifying resources; examining all information sources	• *Collecting resources utilized a book, article, and YouTube.*	• Students try to find out references to build the hydraulic robot.
2nd	• Teacher help the students on carrying out the plan on building a "hydraulic system" *1. There are several part of construction machines: the body, the arm, the forearm and the gripper* *2. The body is the bottom part that moves left and right* *3. The arm is the first arm that moves left, right, up, and down* *4. The forearm is the second arm that moves up and down only* *5. The gripper is a holder to take/move the stuff* *6. The whole body will need something to move such as piston, tube and fluid*	• *Planning of building a hydraulic robot* **(SCIENCE: Systematic observation)**	• Students identify facts about the "hydraulic system" *1. The body* *2. The arm* *3. The forearm* *4. The gripper*

• Teacher help students on listing the equipment *1. Cardboard for whole parts,* *"What size of the cardboard do you need?"* *2. Syringes as a piston,* *"How long the diameter of the syringe and how many syringes that you need?"* *3. Long tube* *"the tube should fit snugly into the opening of the syringe)"* *4. Toothpicks/sticks,* *"are you sure the toothpicks will strong enough?"* *5. superglue, and* *6. water*	*Calculating the size of each part in construction machine's body (the body, the arm, the forearm, the gripper) with teacher's guidance* ***(MATH)***	• Students consider the equipment and the processes based on their knowledge and understanding. *1. The students consider the required energy/force and also the pressure,* *2. The need to ensure that the body of hydraulic robot is strong enough,* *3. The size of the piston is big enough to have a fluid that can support the body's moving*
• Teacher help the students on listing the actions to create the "Hydraulic Robot" *"What kind of design that you want to use?"*	• *Designing hydraulic robot (The step of the experiment)* ***(ENGG, TECH)***	• Students make the steps for experiment "Hydraulic Robot" *1. Finding or creating a*

	"What do you really need to do after deciding the design?" *"Maybe after this, you can start sizing up the body of hydraulic robot? Isn't it?"* *"Remember, before cutting everything, make sure you just finish measuring"*	*perfect design for hydraulic robot* 2. *Cutting the cardboard based on the design* 3. *Size up the initial body of machine before making permanent* 4. *Decide which part of the machine need the piston and tube, how many piston and tube that students need for the whole body* 5. *Measure the length of the tube*
	• Teacher ask the student to prepare the equipment for the next meeting	• Students start showing their awareness and interest, especially in selecting their equipment. In one condition, two students have different selected

			equipment with the other students in one group during their discussion.
	OPEN INQUIRY 2nd Investigation		
3rd	• Teacher supervise the students in conducting the experiment (build hydraulic robot), and reconstructing the “Hydraulic Robot”. *“Try to specify every part, so you will not get confused to start constructing”*	• *Creating “hydraulic robot” without teacher’s guidance*	• Students start the experiment (build hydraulic robot) • Students in a group try to finish cutting the cardboard, measure and cutting the tube, hook the tube and the syringe as a piston  • Students start to build the main body at first, and try to fix it • Students check the main body can move to the left and right easily based on the design

	"are you sure this kind of arm can be strong enough to be with the syringes?" • Teacher continue observing students' activities	• Students try to fill the piston and the tube with fluid/water • Students build the arm, the forearm, and the gripper • Students discuss the result obtained and they identify better ways to improve their design of hydraulic robot (*How to fix the tube to the arm and forearm, which location is appropriate to fix the tube in the arm and forearm, how to make each part is strong enough to have the tube with fluid while they are moving and so on*) • Some groups change whole body from cardboard to plywood, some groups also just double the cardboard to make it strong enough

			• Some groups found difficulties to fix the arm, the forearm, and the gripper, especially when they have to connect these parts with the long tube and piston • Students discussed their result obtained and they identified ways to improve their design • Students show the positive reactions such enthusiasm, awareness, spirit to finish their experiments, to find out a perfect hydraulic robot.
		INQUIRY RESOLUTION 3rd Investigation	
4th	• Teacher supervises the students on finishing the experiment and presenting the result of experiment *"Feel free to change the cardboard"*	• *Evaluating the hydraulic robot created by the students*	• Students understand that the body had to be strong enough. • Students come up with the idea of using plywood and the syringes as a

		piston and looked into how they manage the water-filled without air cavity
	"Good job"	• Students success to design the hydraulic robot with initial problem through engineering design with creating and evaluating their work • Students propose possible technological applications and communicate their result
	"Any group wants to start presentation?" *"Okay group 1 can start"* *"Please show to me and your friends how does your hydraulic robot works"* *"can you use the gripper to take one stuff?"* *"It works/it does not work"*	 • Students present and show how their hydraulic robot can work properly. • Students show satisfaction for their experiment result. Even though some groups still have

	lacking in some parts of their hydraulic robot, but they felt awesome and happy for their work. • Through this work, I could see also the students' interest in doing experiment which is related to their daily life experience, so during and after creating hydraulic robot, they found out how the construction machines work from scientific view.

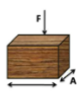
The details of the traditional group are shown in Table 15. This group received traditional instruction that involved reading, listening, and discussion. The students also learned individually before and after the lectures from the teacher in the class.

These two groups were taught by the same teacher and learnt the same concepts in the same number of teaching sessions. This teacher had already participated in a STEM professional development program and had also conducted STEM education.

Table 15. Traditional Instruction Process using Discovery Learning

Meeting	Teacher Activities	Content	Student Activities
1st	• Teacher conducts orientation Greeting, checking student's attendance	• *Introducing the topic "fluid, hydraulic system, hydrostatic*	• Students respond the teacher for attendance

• Teacher try introductory part through questions	*pressure, Pascal law" through several questions*	
"What is fluid?"		*"water"* *"oil"*
"Have you ever heard about hydraulic system?"		*"What is hydraulic system?"*
"What is hydraulic system?"		*"I do not know"*
"What is pressure?"		*"when I push something, it means I give pressure"*
"What is hydrostatic pressure?"		*"mmmmmm, it is the pressure in fluid"*
"How can you say it?" *"okay, then please find out where you can find the use of hydrostatic pressure around you"*		*"Kind of pressures are different depend on the object, for hydrostatic, it is for fluid"*
		• In this meeting, the learning process just started, some of the students showed enthusiasm and some of the students also seemed ignorance.

2nd	• In order to get students' attention, teacher delivered the module that consist of explanation, the example of the question, and the question that students should answer after reading session. • Teacher also read the definition of the concept of static fluid loudly and ask some of the students reading loudly 1. **Fluid** is a substance that continually deforms (flow under an applied shear stress, or external force 2. **Pressure** is a physical force exerted on an object $p = \frac{F}{A}$  p: pressure (N/m^2) F: force (N) A: area (m^2) 3. **Hydrostatic pressure** is the pressure that is	• *Literacy for the science content in the module and book to get definition and equations*	• Students read the module and listen to the teacher's explanation about fluid, hydraulic system, hydrostatic pressure, Pascal law. (Some of the students were listening, but some of the students kept playing and discussing with friends)

exerted by a fluid at equilibrium at a given point within the fluid, due to the force of gravity

$p_h = rgh$ 

p_h: hydrostatic pressure (N/m^2)

ρ: density (kg/m^3)

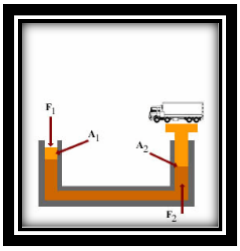
g: acceleration of gravity (m/s^2)

h: liquid depth (m)

4. Pascal Law

The pressure applied to any part of the enclosed liquid will be transmitted equally in all directions through the liquid

$$p_1 = p_2$$
$$\frac{F_1}{A_1} = \frac{F_2}{A_2}$$



- Teacher show the example of static fluid law in daily life: (Hydraulic machines- construction machines,

- Students observed the pictures. (Some of the

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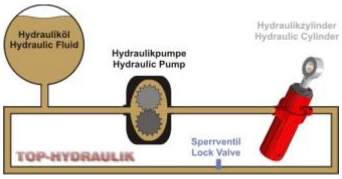
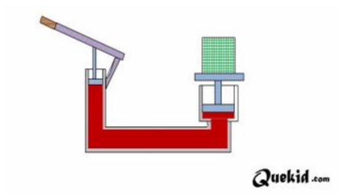
<td>ship, hydraulic brake-submarine).




Teacher tells the students to read the module again and learn about the example of the questions.
In this meeting, the teacher still had difficulties to get students' attention and focus.
</td>
<td></td>
<td>students do not familiar with pictures)</td>
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<tr>
<td>3rd</td>
<td>
Teacher ask the students to find the answer of the questions in module

"A container containing glycerin receives a hydrostatic pressure = 8370</td>
<td>
Training the student in answering the question and remember the equation
</td>
<td>
Students read the module and answer the questions in the worksheet.
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Pa. If the density of glycerin = 1260 km/m^3 and the acceleration of gravity g = 9.8 m/s^2, then the height of the glycerin surface from the bottom of the container is……."

a. 0.5 m
b. 0.57 m
c. 0.68 m
d. 1.04 m
e. 1.14 m

"A vessel 30 cm high was filled with water to the brim. if known air pressure = 10^5 Pa, water density = 1000 kg/m^3 and acceleration due to gravity = 9.8 m/s^2, then the total pressure received at the bottom of the container is……"

a. 0.4 x 10^5 Pa
b. 1.134 x 10^5 Pa
c. 1.04 x 10^5 Pa
d. 1.0294 x 10^5 Pa
e. 1.75 x 10^4 Pa

- Students show enthusiasm with the questions. Some of them think the question was so easy, because

			they already have the equation. However, students who do not focus in the learning process or try to avoid task were still existed in this meeting.
4th	• Teacher checks the students' work and giving feedback	• *Giving feedback through ensuring the correct answer of the students*	*Collaboration* • Students discuss about their answer. *Communication* • Students present their answer from their work in the worksheet • Students make conclusion, correct their wrong answer in their worksheet • Until the last meeting, not all students contributed to the learning process. The students who have correct answer seemed satisfy, and the students who still do not have correct answer seemed disappointed.

Participants, Instrument and Analysis Method

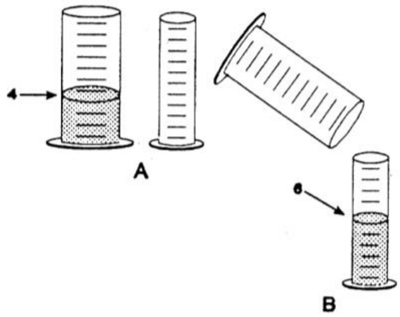
In the third stage, the participants were 63 secondary level students in grade X from one public school in Pangkep Regency, South Sulawesi, Indonesia. Purposive random sampling was used to obtain a sample with the same background.

In this study, the researcher utilized 24 items of two-tier multiple-choice from the Lawson's Classroom Test of Scientific Reasoning (LCTSR), with an example shown in Figure 15. This example covered the proportional skill related to student activities, such as the use of syringes with water inside, in the learning process.

According to Lawson (2000), the purpose of the LCTSR is to (1) measure concrete- and formal-operational reasoning skills; (2) enable the classification of secondary school and college-age students in a short period of time; (3) facilitate scoring; (4) use a format involving physical materials and requiring reading and writing as much as possible; and (5) include a large enough number and variety of problems to assure a high degree of reliability.

Many instruments have been employed to measure students' reasoning skills, but the majority like the Scientific Reasoning Test Version 9 and Test of Scientific Literacy Skills tend to target broad scientific literacy such as the nature of science and ethics in socio-cultural settings (Gormally, Brickman, & Lutz, 2012; Sundre & Thelk, 2010).

5. To the right are drawings of a wide and a narrow cylinder. The cylinders have equally spaced marks on them. Water is poured into the wide cylinder up to the 4th mark (see A). This water rises to the 6th mark when poured into the narrow cylinder (see B).



Both cylinders are emptied (not shown), and water is poured into the wide cylinder up to the 6th mark. *How high would this water rise if it were poured into the empty narrow cylinder?*

a. to about 8
b. to about 9
c. to about 10
d. to about 12
e. none of these answers is correct

6. *because*

a. The answer cannot be determined with the information given.
b. It went up 2 more before, so it will go up 2 more again.
c. It goes up 3 in the narrow for every 2 in the wide.
d. The second cylinder is narrower.
e. One must actually pour the water and observe to find out

Figure 15. Example of LCTSR Two-tier Item Questions in Probabilistic Reasoning Skill

On the other hand, LCTSR has been utilized for nearly three decades and represents a task-based assessment to collect quantitative data on students' reasoning skills and skill development from middle school to college level (Ding, Wei, & Lui, 2016; Lawson, 2000; Stammen, Malone, & Irving, 2018b). LCTSR questions can be used to assess students' scientific reasoning skills in six domains, as explained in Table 16 (Lawson, 1978).

Table 16. Subskills of Reasoning Skills

Scheme Tested	Question Pair	Task Details

Conservation laws	1, 2; 3, 4	Varying the shapes of two identical balls of clay placed on opposite ends of a balance. Examining the displacement volumes of two cylinders of different densities.
Proportional reasoning	5, 6; 7, 8	Pouring water between wide and narrow cylinders and predicting levels.
Control of variables	9, 10; 11, 12; 13, 14	Designing experiments to test the influence of the length of string on the period of a pendulum; Using fruit flies in tubes to examine the influence of red/ blue light and gravity on flies' responses.
Probabilistic reasoning	15, 16; 17, 18	Predicting chances for withdrawing certain coloured wooden blocks from a sack.
Correlational reasoning	19, 20	Predicting whether a correlation exists between the size of the mice and the colour or their tails through presented data
Hypothetical-deductive reasoning	21, 22, 23, 24	Designing experiments to determine why the water rushed up into the glass after the lit candle went out; Designing experiments to determine why red blood cells become smaller after adding a few drops of saltwater.

The items have increasing levels of difficulty. For the evaluation of the test, items 1 to 22 were counted as two-tier questions, and the score assignment assumed that explaining is more laborious than knowing and providing a correct explanation with an incorrect answer implies guessing (see Table 17). Meanwhile, items 23 and 24 were counted as general multiple-choice questions with 11 scoring methods. For further analysis, the researcher used the SPSS program to conduct Analysis of Covariance (ANCOVA) and t-test.

Table 17. Two-tier Multiple-choice Test Scoring Method

Response pattern and score assignment			
“00"	**“01"**	**“10"**	**“11"**
0	0	1	2

Result

In this study, 56 of the 63 students from both groups completed the pre- and post-test of LCTSR. Table 18 shows that the mean score of the control group decreased significantly (from 4.4074 to 2.7931), while the mean score of the STEM group increased slightly (from 3.3871 to 4.4483). This data also showed that the mean score between pre-test traditional group and post-test STEM group do not have much difference.

Table 18. Descriptive Statistics in Both Groups

	Group	N	Mean	Std. Deviation	Std. Error Mean
Pre-test	Traditional	27	4.4074	2.30817	.44421
	STEM	31	3.3871	1.80143	.32355
Post-test	Traditional	27	2.7931	1.80038	.33432
	STEM	29	4.4483	1.45372	.26995

Before conducting ANCOVA, a couple of assumptions were checked to ensure that the covariate fixes the requirement. The first assumption was that the difference between the groups in the pre-test was not statistically significant. The significance of .064 (Table 19) meant that there was no statistically significant difference between the groups in the pre-test. Thus, the first assumption was confirmed.

Table 19. Pre-test Analysis

Dependent Variable: Pretest

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	15.023a	1	15.023	3.567	.064
Intercept	876.747	1	876.747	208.153	.000
Group	15.023	1	15.023	3.567	**.064**
Error	235.873	56	4.212		
Total	1116.000	58			
Corrected Total	250.897	57			

a. R Squared = .060 (Adjusted R Squared = .043)

The second assumption was related to the homogeneity of regression with the control Group*Pre-test. The Group*Pre-test significance of .405 (Table 20) meant it was not significant, thus meeting the homogeneity of regression condition and paving the way for running ANCOVA.

Table 20. Homogeneity of Regression

Dependent Variable: Pre-test

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	44.552a	3	14.851	5.342	.003
Intercept	120.973	1	120.973	43.512	.000
Group	3.331	1	3.331	1.198	.279
Pre-test	2.557	1	2.557	.920	.342
Group * Pre-test	1.958	1	1.958	.704	**.405**
Error	144.573	52	2.780		
Total	925.000	56			
Corrected Total	189.125	55			

a. R Squared = .236 (Adjusted R Squared = .191)

According to the data presented in Table 21, the difference in the post-test value of the reasoning skills between the traditional group and STEM group was statistically significant (Sig. = .000 < .05).

Table 21. Analysis Covariance Result

Dependent Variable: Posttest

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	42.594a	2	21.297	7.703	.001	.225
Intercept	123.776	1	123.776	44.770	.000	.458
Pretest	1.827	1	1.827	.661	.420	.012
Group	42.585	1	42.585	15.403	**.000**	**.225**
Error	146.531	53	2.765			
Total	925.000	56				
Corrected Total	189.125	55				

a. R Squared = .225 (Adjusted R Squared = .196)

To further analyse the effect of the STEM education on each sub-skill, paired sample t test was performed. The traditional group's results, which are presented in Table 22, showed a decline of 36% in the values for reasoning skills, meaning students had less knowledge about the skills than before. The unusual finding of a negative impact was due to a participant error during post-test in the traditional group.

Conservation of weight and volume skills (sig = .631), proportional reasoning skills (sig = .161), and correlation skills (sig = .070) showed no significant difference. Moreover, an improvement in mean scores and statistically significant differences were found only in probabilistic reasoning skill.

Table 22. Paired Sample t-Test of Traditional Group

Reasoning skills	**Pre-test**	**Post-test**	**t**	**Sig.**
Conservation laws	.7037	.6296	.485	.631
Proportional reasoning	.0370	.0000	1.441	.161
Control of variable	.4074	.1111	3.024	.006
Probabilistic reasoning	.0556	.3519	-3.049	.005
Correlation	.4074	.1481	1.892	.070

Hypothetical-deductive	.3951	.0988	3.889	.001

Table 23 presents the t-test results of the students in the STEM group. The mean score of four sub-skills improved (Conservation weight and volume [from .6897 to .7586], proportional reasoning [from .0690 to .1034], control of variable [from .1494 to .1725], and hypothetical-deductive reasoning [from .0690 to .3678]). However, the pre-test and post-test differences were not significant for any of these skills, except hypothetical-deductive reasoning skills, which showed a statistically significant difference (sig = .000) and also the highest improvement in the mean score.

Table 23. Paired Sample t-Test of STEM Group

Reasoning skills	**Pre-test**	**Post-test**	**t**	**Sig.**
Conservation laws	.6897	.7586	-.472	.641
Proportional reasoning	.0690	.1034	-528	.602
Control of variable	.1494	.1725	-.465	.646
Probabilistic reasoning	.3621	.3448	.157	.876
Correlation	.5862	.4138	1.095	.283
Hypothetical-deductive	**.0690**	**.3678**	**-6.666**	**.000**

Discussion and Conclusions

This stage aimed to identify the effect of STEM education on the crucial thinking skills or “reasoning skills” of students in Indonesia using LCTSR assessment that covered the six sub-skills of reasoning skills, including conservation of mass and volume, proportional thinking, control of variables, probabilistic thinking, correlational thinking, and hypothetical-deductive reasoning. In this study, STEM education was defined as an application-oriented approach to teaching science in K-12 education that is built upon the natural connection between science, technology, engineering, and mathematics.

Previous research has elucidated the relationship between STEM education and many aspects of science, including knowledge and skills, especially the improvement of 21st-century skills, thus providing evidence of the positive impact of STEM education in different countries.

Kanadli (2019) and Sari et al. (2017) reported that STEM education primarily contributes to the development of life skills in the skills dimension. It also contributes to the development of psychomotor, problem-solving, science process, critical thinking, engineering and design, inquiry, and 21st-century skills of students. They found the high effect size and frequency gains in the meta-summary study.

In fact, when comparing the subskills' mean score between traditional and STEM group, most of the subskills do not have differences even the result of ANCOVA shows the significant value in the effect of STEM education on the crucial thinking skills. However, the data showed a statistically significant difference between pre- and post-test value of hypothetical-deductive thinking skill in STEM group. It is supported by the previous research in revealing the positive impacts of STEM education on hypothetical-deductive thinking skill.

Further, the final result in this stage also showed unusual finding where the traditional group dropped considerably after the intervention due to the error during post-test in the traditional group. This can be caused by the teacher announcement during the test that the result would not influence students' grade in the school. This information actually becomes the common information for participants in each study to fulfil the research ethics. However, it unexpectedly caused the negative impact to students' interests and the research finding.

The current study highlights that STEM education can contribute to strengthening hypothetical-deductive thinking skill that was crucial in Indonesian' science education and a part of 21st-century skills. During the learning process, students was conducting experiment in designing hydraulic robote that was adapted from real-world application. Through STEM education in this study, the students can catch and imagine during their experiment in case of the relationship between the science concept of hydraulic and their daily life experience of hydraulic robote that they tend to observe around them such as construction machine, dishwashers, barber chairs or dentist chair. This learning process also supports the students' awareness to such interest and informed how the students will utilize their knowledge and skills in the future after learning such science concept eventhough some of the students still have difficulties to focus on the learning process.

On the other hand, traditional group was not conducting experiment. The learning process is only through explanation and reading process then answering questions where almost all students found difficulties in contributing to the learning process. In addition, students who have correct answer seemed satisfy, and the students who do not have correct answer seemed disappointed in the end of the learning process.

STEM education gave experience to students learn how the concept of hydraulic system in science could be developed through engineering design to develop industrial applications for daily life, and gave them the experience of sharing their design ideas, hypotheses, and solutions. These STEM education processes were part of the data collection aspect of this study. However, a lot more needs to be done to improve all the sub-skills of reasoning skills.

This positive learning process was supported by the previous studies that revealed the embedded elements in STEM education such as hand-on activity, mind-on activity, and communication of findings that could have enhanced the students' skills in science. Students used specific examples during the experiment from the real-world activities to reason the answers. This implied that STEM education is instrumental in understanding science concept (Angwal, Saat, & Sathasivam, 2019; Hiong & Osman, 2015; Sari, Alici, & Sen, 2017).

The researcher believed that strengthening crucial thinking skills or reasoning skills through STEM education is not as simple as conducting classes under STEM education. Based on previous research, it is clear that six elements should serve as a guide toward implementing STEM education in class. First, the integration of the four disciplines—science, technology, engineering, and mathematics—should motivate students to make learning personally meaningful. Second, STEM education should encourage students to explore technology to see how it can be used in engineering ideas and designs to solve real-world problems. The third element specifies that STEM should allow students to learn from their failures and engage in redesigning to acquire engineering thinking skills. The fourth element is that STEM education should be a part of the standard science and mathematics curriculum. The fifth and sixth elements require STEM education to adopt a student-centered approach and emphasize teamwork and communication skills (Moore, Glancy, Tank, Kersten, & Smith, 2014). These elements make up a new strategy to challenge students and encourage the shift toward reasoning skills through collaborative learning (Marusic & Slisko, 2012).

However, the researcher said that future research should observe the effects of STEM education on reasoning skills over a long period of time. Students need time to adjust to the new system and process information.

The context for the learning process is also crucial in order to achieve the goal. To this end, teachers should have sufficient knowledge and skills about STEM education and reasoning skills, thus they are able to utilize mathematics and science concepts to define and solve real-world problems, as well as recognize the challenges correlated to create the advance solution.

In STEM education, teachers are the “most knowledgeable other” or “master thinker” in the classroom. Their role is to guide learners in the use of STEM literature to develop authentic thinking skills to come up with solutions. More specifically, teachers are the role models for students when it comes to questioning and being curious; brainstorming ideas; developing plans; generating a litany of educated guesses about a particular situation; and examining theories, ideas, and potential solutions espoused by others (Blue, 2014). Teachers and education support staff should make every effort to support the learning process as students expand their way of thinking to embrace new practices.

CHAPTER 7 CONCLUSIONS AND IMPLICATIONS

Conclusions

This study examined three essential areas of STEM education in Indonesia: core competencies or "crucial thinking skills," instructional design, and effectiveness of STEM. These three essential areas were addressed in the following research questions:

RQ1: What are the most crucial thinking skills for students in science education?

RQ2: To what extent is the instructional design of STEM education (STEM content integration, real-world application, and scaffolding) in Indonesia based on teachers' views?

RQ3: How does STEM education influence the crucial thinking skills of students in Indonesia?

First, this study focused on the crucial thinking skills. It was found through systematic literature review that students are successful in developing some skills. However, some crucial skills were identified. Most of the crucial thinking skills of students exist in the reasoning skills domain, which also covered integrated science process skills and three critical thinking skills, while the remaining skills were present at a good level.

The issue of skills development raises important questions regarding the crucial skills in the cognition stage among the common skills in science education: Science Process Skills, Critical Thinking Skills, and Reasoning Skills. SPS focus on the whole learning process covering basic and integrated SPS. This systematic review found that the crucial sub-skills in SPS are inference, measurement, variable identification and control, operational definition, and explanation, which mostly come under the integrated domain.

CTS focus on the evaluation of the learning process with crucial sub-skills, including data interpretation, inference, and evaluation. Meanwhile, all subskills in RS are essential elements in the learning process and were found to be in the crucial domain. In this domain, students give explanations or reasons based on logical thinking with respect to their hypotheses, statements, data, opinions, theory, experimental design, conclusion, etc. (Lawson, 1995).

Moreover, after identifying their relationships, the researcher revealed the most crucial sub-skills within these three cognitive skills: (i) most of the sub-skills in the integrated science process skill domain (Pedaste et al.); (ii) data interpretation skill (HD1), analysis skill (HD4) and inference skill (HD4); and (iii) explanation skill (EI/HD5) and evaluation skill (HD5). Based on these findings, it can be concluded that crucial cognitive skills in science education are located mostly in the reasoning skills domain, which also cover some sub-skills of SPS and CTS.

Second, the instructional design of STEM education was analyzed based on teachers' perceptions and categorized into three parts: STEM content integration, real-world application of STEM education, and scaffolding of STEM education. The first finding was that STEM education has not existed at the university level for the last 30 years according to the teachers, some of whom did not even know about STEM education before attending the professional development program. This is not surprising given that STEM education has been gaining ground only in the last two years. It has been adopted by the government and is delivered by supervisors through MGMP meetings. In addition, teachers have conducted STEM education even though they were not aware of the idea of STEM education. Yet, implementation is still limited as it largely depends on teachers' interest and motivations because of lack of guidance or direction. Moreover, they have integrated only two or three subjects, not all four.

The teachers who participated in the study confirmed the huge advantages of STEM education in terms of improving students' quality of knowledge and skills, and also mentioned three significant elements of STEM education, i.e. "STEM education is interesting"; "STEM education provides hands-on activities" and; "STEM education is the most updated learning process." They believe that STEM education could give students a better chance to explore real-life issues and also match their interests in and outside the class.

The teachers said that STEM education is more suited to the characteristics of present day students, especially high school students. The emergence of STEM education in the public K-12 education system provides opportunities for students at all levels to master 21st century skills and knowledge by using a variety of activity-based learning models. It also involves inquiry-based, problem-based, and project-based learning that allows students to explore real-world problems simultaneously while developing cross-curriculum skills such as reasoning skills, thinking skills, creativity, collaboration, problem-solving, and research skills, which could be useful in selecting careers in science.

The last finding that emerged was that engineering is the most challenging subject in STEM education, followed by mathematics, technology, and science. Science was probably viewed as the easiest subject because this study interviewed physics teachers who handle science almost every day in their life. All educators need to realize that engineering is the situated context and platform in STEM education.

In addition, the teachers cited some challenges in implementing STEM education, including time constraints, lack of teacher awareness, and lack of technological support. Teachers also mentioned the mismatch between Indonesian curriculum and STEM education. This was narrowed down to the relationship between national examination goals and STEM education goals, wherein students' achievements relied on teachers' success in implementation.

The last challenge cited is the gap between the Indonesian curriculum and STEM education. The teachers noted two things: the content for integrated STEM education and the national examination target. The national examination target in Indonesia places more emphasis on knowledge than skills, which raises the odds of teachers avoiding skills development in the learning process.

Thirdly, STEM education can support the crucial thinking skills only for hypothetical-deductive thinking skill. It showed through the improvement of mean score and a statistically significant difference between pre- and post-test value of this skill in the STEM group.

In conclusion, stage 1 and stage 2 resulted in the current conditions of STEM education in Indonesia. They were confirmed through specific crucial thinking skills and teachers' perception on the instructional design of STEM education. Although stage 3 failed to support the effectiveness of STEM education to solve all crucial thinking skills in Indonesia. However, the mean score in STEM group showed improvement on hypothetical-deductive thinking skills with the significant difference on the score between pre- and post-test. Preparations need to be made and the challenges need to be addressed before the official curriculum from the government is fully implemented.

Implications

The study's findings have some implications. First, a STEM professional development program for science teachers was conducted as part of the study to promote and improve teachers' understanding of STEM education, and teachers may use this fundamental knowledge to support the implementation of STEM education in Indonesia.

Second, the study was conducted in phases based on the STEM education framework that consists of three essential areas: Essential skills or "crucial thinking skills"; instructional design of STEM education; and the effectiveness of STEM education. The first stage of this study identified some crucial thinking skills in 21st century science, which can help the government and teachers formulate strategies to overcome the challenges faced by students in realizing these skills through the exact learning method.

The second stage of this study on the instructional design of STEM education revealed the perceptions of teachers on how STEM education can be implemented in Indonesia and how prepared the country's educational system is to implement STEM.

The effectiveness of STEM education was analyzed in the third stage of this study. The findings revealed the positive effects of STEM education effects only hypothetical-deductive thinking skills as a part of the crucial thinking skills in Indonesia. The Indonesian government needs to consider this information before STEM education is fully implemented.

Limitations and Recommendations

The research findings on the three essential areas in the STEM education framework showed that teachers have positive views regarding the implementation of STEM education in Indonesia and that STEM education has significant positive effects on students' crucial thinking skills. However, there are challenges to STEM implementation, as the study found improvement in only one sub-skill in the crucial thinking skills. This was possibly due to the novelty of the approach for both teachers and students, the short time period from implementation to measurement, the small number of participants, and the post-test error.

In the lesson plan, the researcher tried to utilize all sub-skills in reasoning skills (conservation, proportional, control of variable, probabilistic, correlational, and hypothetical-deductive reasoning). However, some of the sub-skills were found to be dominant during the learning process, including proportional, control of variable, probabilistic, and hypothetical-deductive reasoning skills. Conservation and correlational skills were limited. Additional time is needed to elaborate the learning process in order to measure all sub-skills within reasoning skills.

Further, this study also yielded an unusual finding in that the skill level dropped considerably in the traditional group after the intervention due to an error during post-test in the traditional group. The teacher announced that this test would not influence their score in the school, which was information that had to be provided to participants to fulfil research ethics. However, it negatively affected students' interests and consequently the research finding

Further research is recommended to determine how teachers' understanding and students' results can be maximized through the implementation of STEM education. It is highly recommended that teachers develop their understanding of STEM education and explore how and to what extent it can be implemented in class. More STEM professional development or training programs are needed to create and raise teachers' awareness of STEM education. It is also recommended that future research involve students from not only public schools, but also private schools, and cover diverse topics in physics. In addition, the details of such research should be reported and conducted strictly to avoid any participant error during measurement.

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APPENDIX

THE DETAIL OF STEM PROFESSIONAL DEVELOPMENT PROGRAM

PROFESSIONAL DEVELOPMENT PROGRAM

Location : Pangkep, South Sulawesi, Indonesia

Time : 25th – 30th January 2019 [8.00-17.00 WITA]

Number of participants : 25 In-service teachers [15 experience and 10 newly]

Supervisor : Prof. Tsutaoka Takanori & Dr. Muhammad Arsyad, M.T

Coordinator : Uswatun Hasanah, S.Pd., M.Ed.

TIME	ACTIVITY	Presenter
1st day 8.00-10.00 10.00-12.00 12.00-13.00 13.00-15.00 15.00-15.30 15.30-17.00	**Presentation** The definition of STEM education The importance of STEM education, Lunch The role of technology and engineering in STEM education, Coffee break Teaching strategy in STEM education	• One of the lecturers in the host institution • Uswatun Hasanah, S.Pd., M.Ed.
2nd day 8.00-10.00 10.00-12.00 12.00-13.00 13.00-15.00	**Demonstration** Lunch Demonstration of STEM education utilize the teaching material that is provided by the presenter (2nd session)	• **Uswatun Hasanah, S.Pd., M.Ed.** • Nur Rahmah, S.Pd., M.Ed. • Ainun Najib Al Fatih, S.Pd., M. Ed.
3rd day 8.00-12.00 12.00-13.00 13.00-15.00	**Development** Teacher will conduct two experiments and will be asked to develop lesson plan in STEM education Lunch Discussion, group presentation	• **Uswatun Hasanah, S.Pd., M.Ed.** • Nur Rahmah, S.Pd., M.Ed. • Ainun Najib Al Fatih, S.Pd., M. Ed.

4th day 8.00-12.00 12.00-13.00	**Interview** Delivering questionnaire and interview 9 experience teachers and 5 new teachers Lunch	• **Uswatun Hasanah, S.Pd., M.Ed.** • Nur Rahmah, S.Pd., M.Ed. • Ainun Najib Al Fatih, S.Pd., M. Ed.

1st DAY CONTENT OF PD PROGRAM

In the 1st day PD program, teacher will listen presentations and videos related to STEM education. this part for introductory part for STEM to the participant. The instructor will focus in four points;

1. The definition of STEM education,
2. The importance of STEM education,
3. The role of technology and engineering in STEM education,
4. Teaching strategy in STEM education, example of the STEM learning process

2nd DAY CONTENT OF PD PROGRAM

In this 2nd day PD program, the teachers will watch the demonstration from the instructor related to the simple experiment of STEM related to the content in Indonesia curriculum.

1st demonstration

Global warning demonstration "DIY Space: Water Balloon Demonstration"

Activity details

Subjects: science; primary topic: earth processes; additional topics: earth and space science, earth science, earth, moon and sun; time required: less than 30 mins

Overview

This demonstration uses a water balloon to show how Earth's oceans are absorbing most of the heat being trapped on our warming world.

Materials

1. Several balloons
2. Lighter (be sure it creates a flame rather than a jet)
3. Bottle of water
4. Bucket
5. Safety goggles

Management

Watch the "DIY Space: Water Balloon Demonstration" video tutorial at the top of the page for instructions on doing the demonstration.

Procedures

1. Blow up the balloon and tie it. Ask someone to hold the balloon while you put on safety goggles. Explain to students that the air-filled balloon represents Earth's atmosphere and the flame represents the heat from the sun.
2. Take the balloon and have students stand at least three feet away from you.
3. Hold the bottom of the balloon. Place the lighter's flame onto the balloon, but at a safe distance from where you are holding the balloon. As soon as the flame touches the balloon, the balloon will pop.
4. Now make a water balloon. When filling the balloon, try to remove any air bubbles as placing the flame over an air bubble could cause the balloon to pop prematurely. Explain to students that this balloon represents Earth's oceans.
5. Make sure your safety goggles are still on and hold the balloon over the bucket. Make sure to hold the balloon at the bottom and place the lighter's flame on the balloon, at a safe distance from where you are holding the balloon.
6. Depending on the size of the balloon, the quality and thickness of the rubber, and the presence of any air bubbles, the water-filled balloon should last more than one minute with the flame on it. Be sure to follow any safety instructions on the lighter with regard to how long the lighter may be held lit without cooling off.
7. Eventually it the balloon may pop, so position the bucket to catch the water.
8. Explain to students that this demonstration illustrates how Earth's oceans are absorbing a great deal of the heat generated by climate change. In fact, Earth's oceans are absorbing about 80 to 90 percent of the heat from global warming. Since water can withstand a lot more heat than the atmosphere, the temperature of the oceans isn't changing that much

2nd demonstration

Thermal Expansion Model

Activity Details

Subjects: Science; Primary Topic: Physical Sciences; Additional Topics: Earth And Space, Science, Earth Processes; Time Required: 30 Mins - 1 Hour;

Overview

An important part of understanding sea-level rise is understanding thermal expansion of water. Thermal expansion accounts for about half of the measured global sea-level rise. Students will build a model using everyday items to demonstrate that water expands when heat energy is added.

Materials

Per group of 2-3 students:

1. 1 disposable plastic water bottle, with a flip-top lid, if available. Small bottles made with thicker, sturdier plastic are preferred.
2. 1 clear plastic straw
3. Food coloring
4. Ruler
5. Cutting tool
6. Dark felt-tip pen
7. Thermometer (optional, see Management section)
8. Several low-temperature hot-glue guns, putty or other malleable sealant
9. Paper or cloth towels
10. Safety goggles
11. Heat sources (such as incandescent bulbs, heat lamps, heat pads or the Sun)

Management

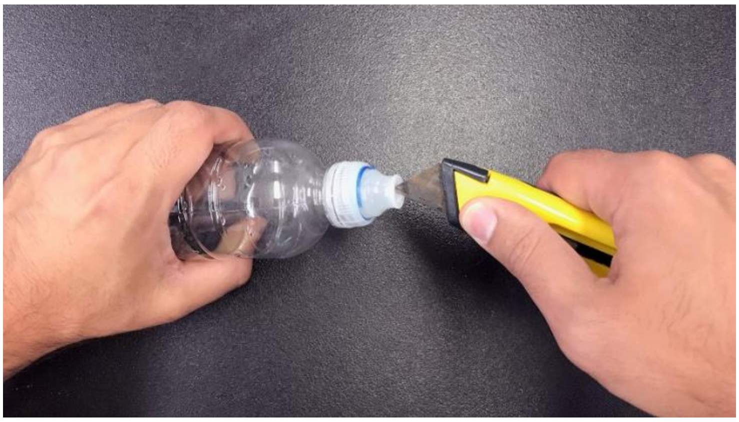
1. Safety! this activity involves the use of sharp cutting instruments and heating elements. To avoid cuts and burns, ensure the safe use of these tools by expressing and modeling appropriate use.
2. A hole will need to be cut into the lid of the water bottle for the straw to fit through. Flip-top lids have a hole, but still require some cutting to open them enough for the straw. The plastic stems inside the flip-top lid can be trimmed out with a sharp blade. A hole can be bored into regular lids with the tip of scissors, a sharp blade or a drill. Depending on student age, skill level and available tools, you may choose to cut the

holes in advance, in class, or have students cut holes on their own during the lesson. Be sure to follow all safety guidelines to protect hands, hair and eyes if using a power drill.

3. Bottles made with thicker, sturdier plastic are preferred. Thin plastic water bottles tend to flex more than thicker, more rigid bottles, and that flexing can alter the water level throughout observations in ways unrelated to thermal expansion.
4. Water will spill in the construction of these models. Prepare desks or work surfaces appropriately and have towels on hand for cleanup.
5. If thermometers are to be used, there are suggested options:
6. Apply an adhesive thermometer strip to the side of the bottle, placed on a side facing away from the heat source
7. Make a small hole in the bottle or cap where a thermometer or heat probe can be inserted into the bottle and the hole sealed. The thermometer should not interfere with the position of the straw as described at the end of Step 3.
8. Different heat sources apply heat to the water with different intensities and larger quantities of water can absorb greater amounts of heat, meaning the time it takes to notice a change in temperature and water height may vary. Consider making and testing one of these models in advance to get an idea of how long it may take. This will help you to determine how long students should wait in between measurements. Record how long it takes for water to rise 0.5 to 1.0 cm and use that time as an approximate interval for Step 7.

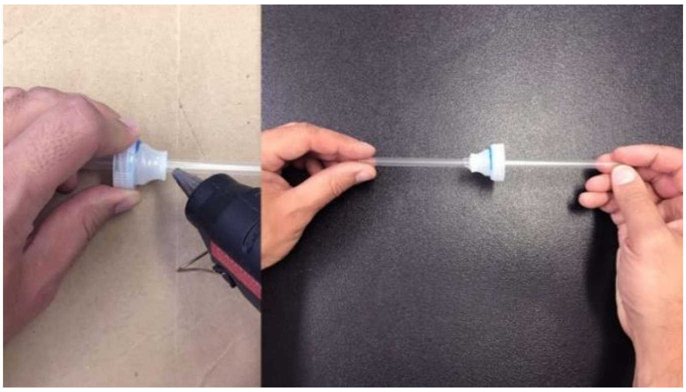
Procedures

1. Discuss climate change and sea-level rise with students. Ask students to identify causes of sea-level rise. If students identify melting ice as a cause of sea-level rise, ask them which type of ice, land ice or sea ice, contributes more to sea-level rise. Consider demonstrating the contribution to sea-level rise by land ice and sea ice using the What's Causing Sea-Level Rise? Land Ice Vs. Sea Ice lesson in conjunction with this activity. If students do not mention thermal expansion, explain that in addition to ice melt, there is another phenomenon that contributes to sea-level rise. The following activity will demonstrate that phenomenon.
2. Depending on students' age and ability, have them cut a straw-size hole in the cap of their water bottle. If done while the cap is still attached to the bottle, students will have more area to grab and can keep their fingers farther from the cutting device.



3. Cut a hole in the lid of the water bottle where the straw will be inserted.

4. Have students insert the straw into the hole. The straw should extend down approximately 2-3 inches into the bottle when the cap is on. (During this step, students can keep the bottle and cap separate.) Using hot glue, putty or another sealant, close any gaps around the straw. Students should avoid skin contact with the glue and be sure to keep the threads of the cap free of glue, putty or sealant. The bottle won't close properly if the threads are not clean. As the glue dries, students should be sure the straw is as close to perpendicular to the top of the lid as possible.



5. Insert and hot glue the straw to the lid of the water bottle.

6. Have students add several drops of food coloring to the water bottle, fill the bottle with water completely to the rim, then top with the straw and cap assembly and tighten. There may be some overflow when the cap is attached. This is ok. The water in the straw should be above the cap, but low enough that when it rises, measurements can be made that indicate how much the water has risen.

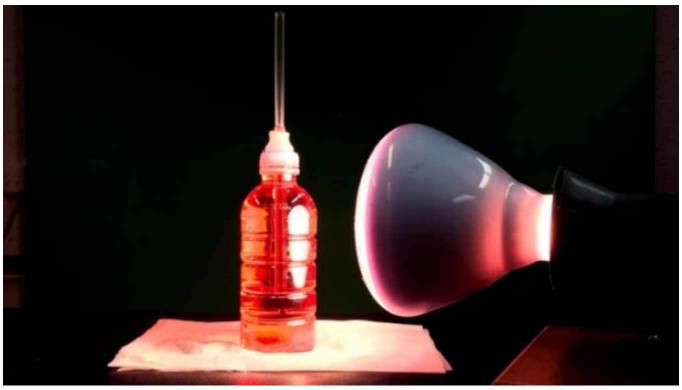
7. Add food coloring to the bottle and fill it completely with water.

8. Tightly attach the straw and cap assembly to the water bottle.

9. Students need to mark the straw to indicate the base, or zero, level of the water. For each measurement, they should align the zero mark on the ruler to this mark. Because moving and squeezing the bottle can change its shape, internal volume and water level, once the line is marked, avoid moving or handling the bottle while the water is warming. Using water bottles with thicker plastic will help minimize the changes to the water level that can occur when the bottle is moved.

10. Mark the starting water level, "zero mark," on the straw.

11. Have students direct a heat source at the bottle or place the bottle in direct sunlight. Because some heat sources apply heat less intensely to the water, the time it takes to notice a change in temperature and water height may vary. Consider making and testing one of these models in advance to get an idea of how long it may take.



12. Direct a heat source at the bottle or place it in direct sunlight.

13. At consistent intervals, students should measure and record the water level compared with the zero mark drawn on the straw, in millimeters, and make note of what’s happening. If using thermometers, students should also record the temperature at these intervals. See Management for determining intervals.

14. At consistent intervals, measure the water level compared with the zero mark.
15. Have students graph the height measurement on paper or using spreadsheet software. If using thermometers, students should graph those data as well.
16. Use one of the thermometer cap assemblies described in "Management" to measure water temperature in addition to the water level.

17. Ask students to describe what they observed in the straw and what they notice on their graph. Students should notice the water level is rising as heat is added to the water. Explain to students that this phenomenon, mentioned in Step 1, is known as thermal expansion.

Discussion

1. Ask students to observe the data and discuss the following questions:
2. What happened to the water level as heat energy was added? Answer: The water level rose as the temperature increased.
3. Explain why the water level in the straw changed over time. What caused this?
   Answer: Water increases in volume when heated. The added energy that came in the form of heat caused the water molecules to move around more. As they moved and bounced off of each other, they took up more space, thereby increasing in volume. As the temperature of the water in the bottle increased, the volume of water in the bottle increased (expanded), which caused the water level in the straw to rise. This process is called thermal expansion.

Assessment

Ask students to identify causes of sea-level rise with sufficient detail to demonstrate understanding:

1. Melting ice is contributing to the rise of sea level. As land ice melts, it runs into the ocean and increases the amount of water in ocean basins. Sea-ice melt does not contribute to sea-level rise, as the melted ice fills the space previously occupied by the frozen sea ice.
2. The ocean's heat capacity allows it to absorb a lot of energy in the form of heat as land and air temperatures rise. When water is warmed, it expands and takes up more space, a phenomenon known as thermal expansion. Thermal expansion increases the volume that ocean water takes up, leading to sea-level rise.

3rd DAY CONTENT OF PD PROGRAM

In this 3rd day, teacher will be asked to conduct STEM experiment and develop the lesson plan for STEM class based on the experiment and what they have learnt from the previous days.

Experiment: Using Light to Study Planets

Activity Details

Subjects: Science, engineering, technology, mathematics ; Primary Topic: Physical Sciences, light and optics; Time Required: longer than 2 hours;

Overview

In this activity, students will build a spectrometer using basic materials to observe the light emitted and absorbed by several sources. This will be used as a model for how NASA uses spectroscopy to determine the nature of elements found on Earth and other planets. For higher grades, this activity can also be used to discuss advanced spectroscopic topics, such as how NASA research is advancing spectroscopic techniques to teach us more about plant life on Earth.

Materials

1. Half of a compact disc
2. Empty cereal box
3. Duct tape (or any completely opaque tape)
4. 4 to 6 light sources (ceiling lights, computer monitors, candles, the sun, etc.)
5. Colored pencils or markers
6. Web camera
7. Laptop computer
8. Theremino spectrometer V2.5
9. Student Worksheet

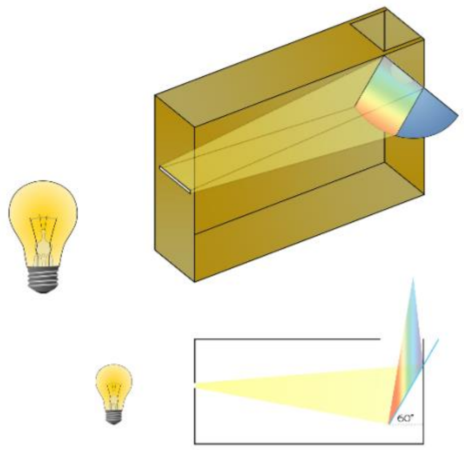
Management

Provide one set of the materials listed above per group.

Safety Note: Break the CDs in half for students. This can be done safely by placing the disc between a book and the edge of a table and breaking the CD along the straight line to ensure a clean break. Wear gardening gloves for additional safety. Put the

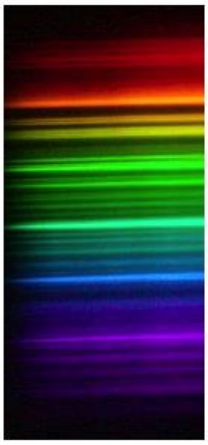
Procedures

1. Have student groups define and differentiate between continuous, absorption and emission spectra using the attached student worksheet and figures before beginning construction of their spectrometer.
2. Put the web camera in the box at a 60-degree angle. Use tape to secure the web camera in the cereal box edge. From the top corner of the cereal box, cut a line the same as the radius of the web camera. Put the CD in front of the lens of the web camera. The CD serves as our diffraction grating. a device that splits colored light into its individual wavelengths, much like a prism. And the web camera will catch the wave and will show through the spectrometer software. So, you can observe the different wavelength for every single light using the software in the laptop computer.



3. Completed spectrometer with light source.
4. Cut out a small square on the top of the cereal box originating from where you cut the CD slits. This will serve as a viewing window.
5. On the opposite end of the diffraction grating, about an inch or so down the from the top, cut a small slit from left to right. This can be done length-wise or width-wise on the box. Emphasize to the students that the cut should be as clean and narrow as possible as it will determine the quality of the spectra observed.
6. Use tape to mend the slit as needed, leaving only 1 to 2 millimeters of open space for light to enter the slit. If the slit is too narrow, the spectra will appear dim. If the slit is too broad, the spectra will appear blurry.

7. Be sure the cereal box is sealed so that the only way light can enter is from the slit or the viewing window.



8. Step 9: Light source and view through the spectrometer.

9. Point the slit toward the light sources to be explored – the closer the better. For sunlight, you can try reflecting the light off of a white sheet of paper and changing the distance of the paper from your device. Be certain not to point your device directly at the sun or put your eyes at risk! There is enough light on a sunny day for the device to work indirectly.

10. Have students fill out their worksheet, drawing in their absorption spectra and predicted emission spectra. Encourage students to capture line resolution by indicating whether the lines are broad or thin, blurry or clear.

Discussion

With this simple spectrometer, you can see a few interesting light sources, but it would be nice to see the spectra of many things that aren't easily found in your neighborhood. Students can discuss also what impact our atmosphere has on the colors we observe.

Experiment: Building rockets at school

Activity Details

Subjects: Science, technology, engineering, mathematics; Primary Topic: Newton's Law, Gravity; Time Required: 2 hours;

Overview

In this activity, participants will build a rocket using basic materials to tie together many different concepts in physics-in particular, the equations of motion linking velocity, acceleration, distance and time, as well as the aerodynamics. It also provides an axciting introduction to what is is like to be a scientist: designing rocket from theoretical principles, carrying out an experiment by launching rockets, and finally analyzing the results, drawing conclusions and identifying points for improvement for the future.

Material

1. Two pieces of A4 paper
2. Scissors
3. Sticky tape
4. Putty or plasticine
5. Mini camera

Management

the stability of the rocket depends on where the center of gravity and the center of pressure are in relation to each other. For a stable rocket, the center of gravity should be in front of the center of pressure at all times. Simply put, the center of pressure is where the sum of all drag forces acts.

If the center of pressure is in front the center of gravity, a turning moment will occur, causing the rocket to flip over in mid-flight. This is why ballast is usually applied to the nosecone.

If the relative distance between the center of pressure is too large, either because too much mass has been applied to the front of the rocket or because the fins are oversized, the rocket will be more sensitive to wind.

Procedures

The aim when building the rocket is to minimize drag (air resistance). Drag is mostly dependent on the velocity, but also on the frontal surface area of the rocket and its overall shape-important considerations when designing a rocket.

1. Rocket body;
    - Roll one piece of paper into a cylinder to form the body of the rocket.
    - Seal one of the open ends of the cylinder with tape, making the front of the rocket. Check that the seal is airtight by blowing into it.
2. Nosecone;
    - Frim the other piece of paper, cut out a circle (diameter 7.5 cm), then cut a sector of approximately 90 degrees from the circle.
    - Twist the remaining piece into a cone.
    - Make hole in the center of the body, put the mini camera inside and keep the balance and place a small ball of putty inside the tip of the cone before fastening the cone to the sealed end of the rocket body with tape.
3. Fins;

- Cut four paper triangles of exactly the same size and fold one of the sides of each triangle to form a flap, which will be attached to the rocket.
- Participant should think about the optimal shape of the fin-some fin profiles will cause the rocket to spin more, others less. Is spin desirable in a rocket?
- To launch the rocket, there are many types of launcher, but all are essentially a stable tube with the same three constituents.
- A compression chamber in which that air is pressurized, using either a compressor or bicycle pump with a built-in pressure gauge.
- A launch tube on which the rocket is placed. An adjustable launch tube allows the angle of elevation of the rocket at take-off to be determined.
- A mechanism to release the pressure from the compression chamber into the launch tube. The sudden release of pressurized air launches the rocket.
- When launching the rocket, note that the higher air pressure does not necessary lead to better flight performances. This is because aerodynamic drag on the rocket increases with velocity; the rocket's fins may be distorted, increasing drag and reducing performance.
- Before deciding the angle at which to launch the rocket, you should think about how angle of elevation affects the total distance travelled and the rocket's apogee

Discussion

1. After the launch, participants can analyze the rocket's trajectory to calculate the maximum height (apogee) attained by the rocket and also its initial velocity. To perform the trajectory analysis, some measurements need to be taken before the launch:
2. Length of the rocket body (h, in m)
3. Inner diameter of the launch tube (Di, in m)
4. Pressure within the launcher (P, in pascal) before launch while the valve is closed; this can be read off the foot pump or the compressor and converted from psi or bar into pascal. (the pressure is assumed to be constant across the length of the tube)
5. Mass of the rocket (mr, in kg)
6. Angle of elevation (ϴ, in degrees)
7. And after everything is done. The participants need to make reflection on lesson implementation and make a group presentation.

4th DAY CONTENT OF PD PROGRAM

Interview for professional development participants related to their perception about STEM education.

Research design : Qualitative research, triangulation strategy [past experiences, current experiences, reflection on the meaning]

Aims : Observing how is the teacher's perception about the probability of STEM education implementation in Indonesia especially in rural area

1. How is your pre-service teacher training like? Does the STEM exist?
2. Have you ever heard about STEM education before the workshop?
3. How do you think about STEM education comparing to the conventional instruction?
4. What value that you can get from STEM education? Which subject is the most difficult?
5. What do you think about STEM impact to the student's knowledge and skill?
6. What challenges that you think might be found in STEM education through physics class especially in rural area?

TRANSCRIBING INTERVIEW

Interview for professional development participants related to their perception about STEM education.

Research design : Qualitative research

Aim : Observing how is the teacher's perception about the probability of STEM education implementation in Indonesia especially in rural area

1. Have you ever heard about STEM education before the professional development program?
2. How did your pre-service teacher training like? Did the STEM exist?
3. How do you think about STEM education comparing to conventional instruction?
4. Which subject is the most difficult in STEM education?
5. What do you think about STEM impact on the student's achievement?
6. What challenges that you think might be found in STEM education through physics class?

Sample	EX	NW	EX	EX	NW	EX	EX	EX	EX	NW	NW	EX	EX	NW
Question	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. How did your pre-service teacher training like? Did the STEM exist?	No	No	I have ever heard and experienced, but this is the first time for to call it STEM education	I tend to conduct STEM education in my class, but I don't know that those kinds of things called as STEM education	I have ever heard and experienced, but this is the first time for to call it STEM education	No	No	No	I tend to conduct STEM education in my class, but I don't know that those kinds of things called as STEM education	No	No	No	No	No
2. Have you ever heard about STEM education before professional development program?	Never, this seminar is the first time I heard about STEM	Never	Never	I have ever heard before	I have ever heard about STEM education	Never	Never	Second time	First time	I have ever heard before from friend	I have ever heard before	Second time	Second time, from friends	Never

		education													
3.	How do you think about STEM education comparing to the conventional instruction?	STEM education is most comfortable for both teacher and students. It can build more relationship for both actor in the learning process.	Students recently are different to 10 years ago' students. Students become more active and love playing something. sometimes they cannot be controlled using traditional learning method. STEM education emerges as a new one with interesting activity. I believe it will help for us as physics teacher.	STEM Education is more complete compare to traditional method.	In our school, we commonly conduct experiment but mostly simple experiment, so STEM education has a big chance to conduct compare to traditional method.	STEM education is very good and has a big chance to be implemented, meanwhile we cannot skip our school goals. If we want to say the probability of STEM education in the village, it still finds difficulty, it is more appropriate to the urban area compare to the rural area.	STEM education is appropriate with physics learning process. Students can learn directly about the implementation of content.	Interesting. Because STEM education gives a challenge for us as a teacher and students can easily understand the concept of physics that we try to explain.	Students tend to fin difficulty in physics, but through STEM education, they may feel easier because it will use demonstration and experiments	STEM is interesting, especially for students, it can build the creativity of student, but we must face the fact of curriculum and national examination.	STEM education is appropriate especially for physics class.	STEM education consists of four subject that complete each other	It is totally different to the conventional learning, because students can directly implement the concept to their daily life	It is totally different to the conventional learning, because in STEM education we do not need specific laboratories	Student will do the learning process directly
4.	Which subject is the most difficult?	It is interesting, Easier to the	It is interesting, Easier to the	STEM education is more interesting for student	STEM education is interesting, Easier to the	Very good, Easier to the most difficult;	Interesting, Easier to the most	Interesting, Easier to the most	Interesting, Easier to the most	Interesting, Easier to the most difficult;	Approachable, Easier to the most	Interesting, Easier to the most difficult;	Interesting, Easier to the most	Good, interesting, Easier to the most difficul	Good, Easier to the most difficult; science

	most difficult; Science, mathematics, technology, **engineering.**	most difficult; Science, mathematics, technology, **engineering.** Because as I myself, I doubt myself that I can implement engineering in my class.	s, Easier to the most difficult; Science, technology, engineering, **mathematics**.	most difficult; Science, technology, engineering, **mathematics**.	Mathematics, it is simpler, Science, because my class is physics, technology, because students already easily find and use technology, **engineering**, because it need process, more time.	difficult; Science, mathematics, technology, **engineering**.	difficult; Science, mathematics, technology, **engineering**.	difficult; Science, mathematics, technology, **engineering**.	science, technology, engineering, **mathematics**.	difficult; science, mathematics, engineering, **technology**	science, technology, engineering, **mathematics**	difficult; science; mathematics, engineering, **technology**	t; science, engineering, mathematics, **technology**	, technology, mathematics, **engineering**
5. What do you think about STEM impact to the student's achievement?	STEM education will give more for student's development especially student's skill	Knowledge and skill of students have connected each other through STEM education.	Skill	Skill		STEM education has relationship to the knowledge and skill of the students	STEM Education will help student to improve knowledge and skill of the student.	STEM Education will help student to improve knowledge and skill of the student.	Students will improve their skill through STEM education	Science help students to get the knowledge, in case of mathematics engineering and technology will support improvement of student's skill	STEM education is very important for students and should be implemented. STEM education will directly help the student not only to the theory but also to the daily life problem	The experiment in STEM education can help to improve both, knowledge and skills	The experiment in STEM education can help to improve both, knowledge and skills	With experiment, STEM education can improve the skill of students
6. What challenges that you think might be	STEM education is	Time limitation, the natio	Time management is the most	Time limitation		Students are lazy to	STEM education will	Time limitation depends	Time limitation and also the	STEM education need	It really depends on the	Teaching material can	Teaching material	Teaching material

found in STEM education through physics class?	not difficult as I imagine, some teaching material are easy to find, so it is possible to conduct, but if we talk about the all national curriculum, not all content in physics can be implemented in integrated STEM education. some teachers also have difficulty in case of ability, teachers need more effort to help student with	nal curriculum does not give enough time for conducting experiment, so sometimes, students need to finish their experiment at home or in the break time.	challenges point. The second one is teaching material, but it depends on the topic.			read, lack of technology due to kind of school (boarding school). But in case of STEM education, it really depends on teachers. Teacher should be brave to make more effort for their learning process.	find a challenge in timing	on the topic.	result of national examination. Those reason will make teacher always skip STEM education, so we have to have strong motivation, all teacher should realize that important point for students is not only the examination result, but also those creativity	support from all in education field, STEM education also needs more preparation.	teacher strategy, it will be full of limitation if the teacher is too lazy and careless about the effective teaching method.	still limit the teacher as well as students for implementing STEM education		

	the best quali ty													

Sample I (EXPERIENCE TEACHER)

1. Never
2. Never, this seminar is the first time I heard about STEM education
3. STEM education is most comfortable for both teacher and students. It can build more relationship for both actor in the learning process.
4. It is interesting
5. Easier to the most difficult; Science, mathematics, technology, **engineering.**
6. STEM education will give more for student's development especially student's skill
7. STEM education is not difficult as I imagine, some teaching material are easy to find, so it is possible to conduct, but if we talk about the all national curriculum, not all content in physics can be implemented in integrated STEM education. some teachers also have difficulty in case of ability, teachers need more effort to help student with the best quality

Sample II (NEWLY TEACHER)

1. Never
2. First time
3. Students recently are different to 10 years ago' students. Students become more active and love playing something. sometimes they cannot be controlled using traditional learning method. STEM education emerges as a new one with interesting activity. I believe it will help for us as physics teacher.
4. It is interesting
5. Easier to the most difficult; Science, mathematics, technology, **engineering.** Because as I myself, I doubt myself that I can implement engineering in my class.
6. Knowledge and skill of students have connected each other through STEM education.
7. Time limitation, the national curriculum does not give enough time for conducting experiment, so sometimes, students need to finish their experiment at home or in the break time.

Sample III (EXPERIENCE TEACHER)

1. I think I have ever heard and experienced, but this is the first time for to call it STEM education
2. First time
3. STEM Education is more complete compare to traditional method.
4. STEM education is more interesting for students
5. Easier to the most difficult; Science, technology, engineering, **mathematics**.
6. Skill
7. Time management is the most challenges point. The second one is teaching material, but it depends on the topic.

Sample IV (EXPERIENCE TEACHER)

1. I tend to conduct STEM education in my class, but I don’t know that those kinds of things called as STEM education
2. I have ever heard before
3. In our school, we commonly conduct experiment but mostly simple experiment, so STEM education has a big chance to conduct compare to traditional method.
4. STEM education is interesting
5. Easier to the most difficult; Science, technology, engineering, **mathematics**.
6. Skill
7. Time limitation

Sample V (NEWLY TEACHER)
1. I think I have ever heard and experienced, but this is the first time for to call it STEM education
2. I have ever heard about STEM education
3. STEM education is very good and has a big chance to be implemented, meanwhile we cannot skip our school goals. If we want to say the probability of STEM education in the village, it still finds difficulty, it is more appropriate to the urban area compare to the rural area.
4. Very good
5. Easier to the most difficult; Mathematics, it is simpler, Science, because my class is physics, technology, because students already easily find and use technology, engineering, because it need process, more time.

Sample VI (EXPERIENCE TEACHER)
1. First time
2. First time
3. STEM education is appropriate with physics learning process. Students can learn directly about the implementation of content.
4. Interesting
5. Easier to the most difficult; Science, mathematics, technology, **engineering**.
6. STEM education has relationship to the knowledge and skill of the students
7. Students are lazy to read, lack of technology due to kind of school (boarding school). But in case of STEM education, it really depends on teachers. Teacher should be brave to make more effort for their learning process.

Sample VII (EXPERIENCE TEACHER),
1. First time
2. First time
3. Interesting. Because STEM education gives a challenge for us as a teacher and students can easily understand the concept of physics that we try to explain.
4. Interesting
5. Easier to the most difficult; Science, mathematics, technology, **engineering**.
6. STEM Education will help student to improve knowledge and skill of the student.
7. STEM education will find a challenge in timing

Sample VIII (EXPERIENCE TEACHER),
1. Second time

2. Second time
3. Students tend to fin difficulty in physics, but through STEM education, they may feel easier because it will use demonstration and experiments
4. Interesting
5. Easier to the most difficult; Science, mathematics, technology, **engineering**.
6. STEM Education will help student to improve knowledge and skill of the student.
7. Time limitation, depends on the topic.

Sample IX (EXPERIENCE TEACHER),
1. I tend to conduct STEM education in my class, but I don't know that those kinds of things called as STEM education
2. First time
3. STEM is interesting, especially for students, it can build the creativity of student, but we must face the fact of curriculum and national examination.
4. Interesting
5. Easier to the most difficult; science, technology, engineering, **mathematics**.
6. Students will improve their skill through STEM education
7. Time limitation and also the result of national examination. Those reason will make teacher always skip STEM education, so we have to have strong motivation, all teacher should realize that important point for students is not only the examination result, but also those creativity.

Sample X (NEWLY TEACHER)
1. First time
2. I have ever heard before from friend
3. STEM education is appropriate especially for physics class.
4. Approachable
5. Easier to the most difficult; science, mathematics, engineering, technology
6. Science help students to get the knowledge, in case of mathematics engineering and technology will support improvement of student's skill
7. STEM education need support from all in education field, STEM education also needs more preparation.

Sample XI (NEWLY TEACHER)
1. First time
2. I have ever heard before
3. STEM education consists of four subject that complete each other
4. Interesting
5. Easier to the most difficult; science, technology, engineering, mathematics
6. STEM education is very important for students and should be implemented. STEM education will directly help the student not only to the theory but also to the daily life problem
7. It really depends on the teacher strategy, it will be full of limitation if the teacher is too lazy and careless about the effective teaching method.

Sample XII (EXPERIENCE TEACHER),
1. First time

2. Second time
3. It is totally different to the conventional learning, because students can directly implement the concept to their daily life
4. Interesting
5. Easier to the most difficult; science; mathematics, engineering, technology
6. The experiment in STEM education can help to improve both, knowledge and skills
7. Teaching material can still limit the teacher as well as students for implementing STEM education

Sample XIII (EXPERIENCE TEACHER),

1. First time
2. Second time, from friends
3. It is totally different to the conventional learning, because in STEM education we do not need specific laboratories
4. Good, interesting
5. Easier to the most difficult; science, engineering, mathematics, technology
6. The experiment in STEM education can help to improve both, knowledge and skills
7. Teaching material

Sample XIV (NEWLY TEACHER)

1. First time
2. First time
3. Student will do the learning process directly
4. Good
5. Easier to the most difficult; science, technology, mathematics, engineering
6. With experiment, STEM education can improve the skill of students
7. Teaching material

INTERVIEW SUMMARY

Question	Summary Experience teacher	Summary of Newly teacher	Summary
STEM Content Integration			
2. How did your pre-service teacher training like? Did the STEM exist?	**Six of nine** experience teachers said that they have never found such kind of STEM education information during their pre-service training and also never conduct STEM class, this is the first time for them to know and conduct STEM education. **Three of nine** experience teachers said that they tent to conduct STEM education in their classes, but they do not know that it is called STEM education. It may	**Five** newly teachers said that they have never experienced STEM education during their pre-service training, but one of them said that he/she tent to conduct STEM education in their classes, but he/she does not know that it is called STEM education.	STEM education still does not exist in the University level, especially in pre-service teacher training in Indonesia for the last 30 years. Even though, teachers tend to conduct STEM class without knowing that those classes as called STEM education.

	be not integrated STEM education, because we did not complete four subjects, sometimes only two and three subjects include, and we built the connection between the learning and students' daily life experience.		
3. Have you ever heard about STEM education before the professional development program?	**Four** of nine experience teachers have never heard about STEM education before, and **five** of them heard about it recently, but only from a friend, supervisor, not a seminar, etc.	**Two** of five have never heard about STEM education before, **Three** of them heard about it recently, but only from a friend, not a seminar, supervisor, etc.	STEM Education was spelled out as a new method in Indonesian' Education. Most of physics' teachers just got the information about STEM education from the last two years; friend and supervisor, but not officially form the government. The government started to promote STEM education this year through the seminar, but only for a few teachers around Indonesia.
Real-world Application			
• How do you think about STEM education	-	-	STEM Education is more challenging comparing to conventional instruction. Experience teacher, as well as

comparing to conventional instruction?			new teacher, believe that STEM education can give a chance student to explore, experience more based on real life. The teacher said that recent students are different from 10 years ago. Students become more active and love playing. Sometimes they cannot be controlled using traditional learning method. STEM education emerges as a new one with an enjoyable activity which matches the student's habit and also the workplace need STEM education is appropriate with the physics learning process, but we have to realize also that we need effort, **One** newly teacher said that ‘we cannot skip our school goals. If we want to say the probability of STEM education in the village, we may find difficulties. It is more appropriate to the urban area compare to the rural area to try it with a simple way like what we did today on the PD program.

			Also, we need to take it seriously, not just as a temporary curriculum so that we can work hard for the preparation as well as the process. Most teachers think that work too hard will not be suitable for them because even they work hard to understand the curriculum, it will change sooner, including in the implementation of STEM Education
Scaffolding of STEM Education			
4. Which subject is the most difficult in STEM education?	Nice, Interesting. Four engineering, three mathematics, two technology	Interesting. Three engineering, one mathematics, one technology	STEM education is engaging, not only for the teachers but also for students. From the teachers' view, engineering is the most challenging domain to be implemented. Because as a science teacher in senior high school, engineering still uncommon for us, we do believe that we can implement it, but we do also believe among four subject, it requires more training, energy, time, attention from government and teachers
5. What do you think about STEM impact	-	-	Both experience and newly teacher believe that STEM Education can improve both

on the student's achievement?			knowledge and skill; it will be with some challenges, limitations.
6. What challenges that you think might be found in STEM education through physics class?	-	-	• Time limitation in the class and after class, • Teacher careless about the effective teaching method, • Limited technology, • Content of national curriculum that may be only a few contents for integrated STEM education • The main goal of a national examination in Indonesia.

LAWSON'S CLASSROOM TEST OF SCIENTIFIC REASONING

by Anton (Tony) Lawson, Emeritus Professor of Biology, Arizona State University multiple choice version - 2000

Suggestions for high school science teachers (compiled in June 2013 by Jane Jackson, Dept. of Physics, Arizona State University, and intended for users of Modeling Instruction in physics.)

Of fundamental importance:

* **Keep it confidential!** i.e., preserve its integrity.

* Treat it as you treat the FCI: 30 minutes, closed book, no notes; don't go over it after students have taken it, etc.

How much of the test to give?

Teachers can submit classroom data for all 24 questions (and be given a comparison with national norms) at John Deming's website:

https://sites.google.com/site/wsuinquiryinstruction/home/ctsr-data-entry-form

9-2013: Teachers can record scores, analyze them, and correlate them with the FCI, by downloading a spreadsheet called assessssv5b.xls at

http://modeling.asu.edu/R&E/Research.html. Prof. James Vesenka developed it.

Warning: questions #21 - 24 are quite wordy and thus may take considerable time. If you teach a first year course in high school, be warned that students might lose interest and 'blow them off'.

When to give the test: It's best to give pre- and post-tests for both FCI and Lawson test. The FCI *post-test* is more important. The Lawson *pre-test* can indicate students' starting level of reasoning.

Grading the test: It has 24 multiple-choice questions. John Deming scores them in pairs; e.g. questions 1 and 2 count as one item. Since questions 23 and 24 are independent, each of them counts as one item. Thus the CTSR has 13 items (i.e., a maximum score of 13).

Submitting your data to ASU: If you've had a Modelling Workshop at Arizona State University or you were in the NSF Modelling Workshop Project (1995-1999), kindly send your student data to Jane.Jackson@asu.edu, preferably in an Excel spreadsheet (like assessssv5b.xls) with each student's ID number or initials, pre-test and post-test score. Please include their gender.

Also, race/ethnicity, if possible (i.e., note if any student appears to be Hispanic, Black, or American Indian). Don't send their names - we must preserve anonymity, to meet Federal requirements.

ANSWER KEY (keep it confidential!)

1. B
2. D
3. A
4. E
5. B
6. C
7. D
8. A
9. E
10. C
11. B
12. A
13. C
14. D
15. C
16. A
17. B
18. E
19. A
20. D
21. A
22. A
23. A
24. B

CLASSROOM TEST OF SCIENTIFIC REASONING

Directions to Students:

This is a test of your ability to apply aspects of scientific and mathematical reasoning to analyze a situation to make a prediction or solve a problem. Make a dark mark on the answer sheet for the best answer for each item. If you do not fully understand what is being asked in an item, please ask the test administrator for clarification.

DO NOT OPEN THIS BOOKLET UNTIL YOU ARE TOLD TO DO SO

Revised Edition: August 2000 by Anton E. Lawson, Arizona State University. Based on: Lawson, A.E. 1978. Development and validation of the classroom test of formal reasoning. *Journal of Research in Science Teaching*, 15(1): 11-24.

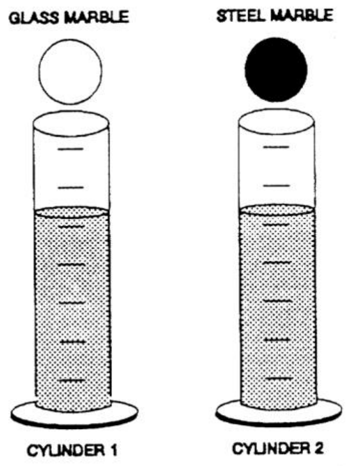
1. Suppose you are given two clay balls of equal size and shape. The two clay balls also weigh the same. One ball is flattened into a pancake-shaped piece. *Which of these statements is correct?*
    a. The pancake-shaped piece weighs more than the ball
    b. The two pieces still weigh the same
    c. The ball weighs more than the pancake-shaped piece

2. *because*
    a. the flattened piece covers a larger area.
    b. the ball pushes down more on one spot.
    c. when something is flattened it loses weight.
    d. clay has not been added or taken away.
    e. when something is flattened it gains weight.

3. To the right are drawings of two cylinders filled to the same level with water. The cylinders are identical in size and shape.

   Also shown at the right are two marbles, one glass and one steel. The marbles are the same size but the steel one is much heavier than the glass one.

   When the glass marble is put into Cylinder 1 it sinks to the bottom and the water level rises to the 6th mark. *If we put the steel marble into Cylinder 2, the water will rise*

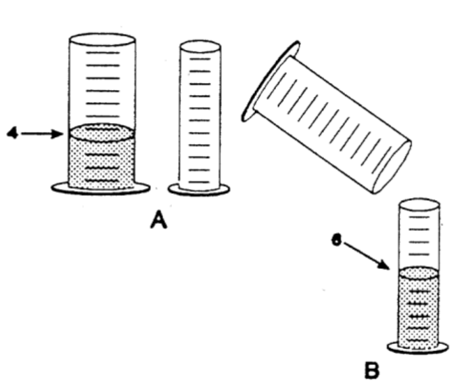


   a. to the same level as it did in Cylinder 1
   b. to a higher level than it did in Cylinder 1
   c. to a lower level than it did in Cylinder 1

4. *because*

   a. the steel marble will sink faster.
   b. the marbles are made of different materials.
   c. the steel marble is heavier than the glass marble.
   d. the glass marble creates less pressure.
   e. the marbles are the same size.

5. To the right are drawings of a wide and a narrow cylinder. The cylinders have equally spaced marks on them. Water is poured into the wide cylinder up to the 4th mark (see A). This water rises to the 6th mark when poured into the narrow cylinder (see B).



   Both cylinders are emptied (not shown) and water is poured into the wide cylinder up to the 6th mark. *How high would this water rise if it were poured into the empty narrow cylinder?*

a. to about 8
b. to about 9
c. to about 10
d. to about 12
e. none of these answers is correct

6. *because*

a. the answer cannot be determined with the information given.
b. it went up 2 more before, so it will go up 2 more again.
c. it goes up 3 in the narrow for every 2 in the wide.
d. the second cylinder is narrower.
e. one must actually pour the water and observe to find out.

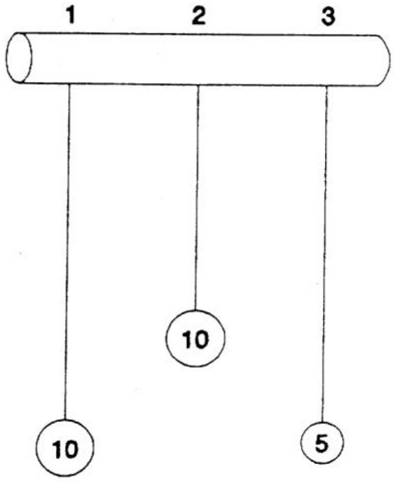
7. Water is now poured into the narrow cylinder (described in Item 5 above) up to the 11th mark. *How high would this water rise if it were poured into the empty wide cylinder?*

a. to71/2
b. to9
c. to8
d. to71/3
e. none of these answers is correct

8. *because*

a. the ratios must stay the same.
b. one must actually pour the water and observe to find out.
c. the answer cannot be determined with the information given.
d. it was 2 less before so it will be 2 less again.
e. you subtract 2 from the wide for every 3 from the narrow.

9. At the right are drawings of three strings hanging from a bar. The three strings have metal weights attached to their ends. String 1 and String 3 are the same length. String 2 is shorter. A 10 unit weight is attached to the end of String 1. A 10 unit weight is also attached to the end of String 2. A 5 unit weight is attached to the end of String 3. The strings (and attached weights) can be swung back and forth and the time it takes to make a swing can be timed.



Suppose you want to find out whether the length of the string has an effect on the time it takes to swing back and forth. *Which strings would you use to find out?*

a. only one string
b. all three strings
c. 2and3
d. 1and3
e. 1and2

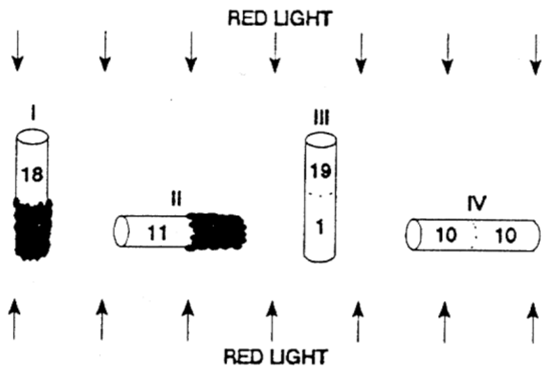
10. *because*

a. you must use the longest strings.
b. you must compare strings with both light and heavy weights.
c. only the lengths differ.
d. to make all possible comparisons.
e. the weights differ.

11. Twenty fruit flies are placed in each of four glass tubes. The tubes are sealed. Tubes I and II are partially covered with black paper; Tubes III and IV are not covered. The tubes are placed as shown. Then they are exposed to red light for five minutes. The number of flies in the uncovered part of each tube is shown in the drawing.

This experiment shows that flies respond to (respond means move to or away from):

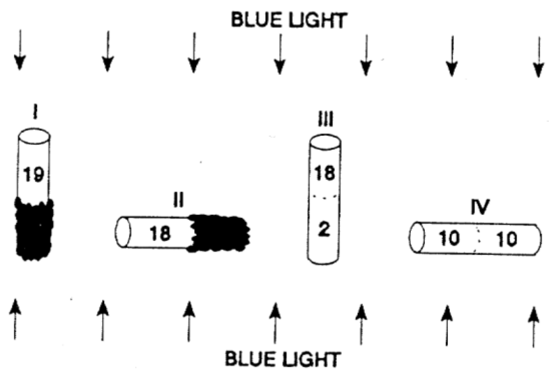
a. red light but not gravity
b. gravity but not red light
c. both red light and gravity
d. neither red light nor gravity



12. *because*

a. most flies are in the upper end of Tube III but spread about evenly in Tube II.
b. most flies did not go to the bottom of Tubes I and III.
c. the flies need light to see and must fly against gravity.
d. the majority of flies are in the upper ends and in the lighted ends of the tubes.
e. some flies are in both ends of each tube.

13. In a second experiment, a different kind of fly and blue light was used. The results are shown in the drawing.



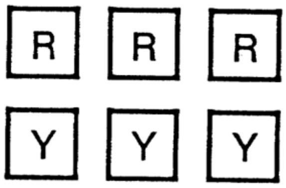
These data show that these flies respond to (respond means move to or away from):

a. blue light but not gravity
b. gravity but not blue light
c. both blue light and gravity
d. neither blue light nor gravity

14. *because*

a. some flies are in both ends of each tube.
b. the flies need light to see and must fly against gravity.
c. the flies are spread about evenly in Tube IV and in the upper end of Tube III.
d. most flies are in the lighted end of Tube II but do not go down in Tubes I and III.
e. most flies are in the upper end of Tube I and the lighted end of Tube II.

15. Six square pieces of wood are put into a cloth bag and mixed about. The six pieces are identical in size and shape; however, three pieces are red and three are yellow. Suppose someone reaches into the bag (without looking) and pulls out one piece. *What are the chances that the piece is red?*

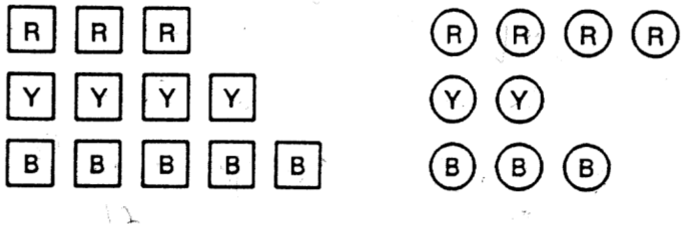


a. 1 chance out of 6
b. 1 chance out of 3
c. 1 chance out of 2
d. 1 chance out of 1
e. cannot be determined

16. *because*

a. 3 out of 6 pieces are red.
b. there is no way to tell which piece will be picked.
c. only 1 piece of the 6 in the bag is picked.
d. all 6 pieces are identical in size and shape.
e. only 1 red piece can be picked out of the 3 red pieces.

17. Three red square pieces of wood, four yellow square pieces, and five blue square pieces are put into a cloth bag. Four red round pieces, two yellow round pieces, and three blue round pieces are also put into the bag. All the pieces are then mixed about. Suppose someone reaches into the bag (without looking and without feeling for a particular shape piece) and pulls out one piece.



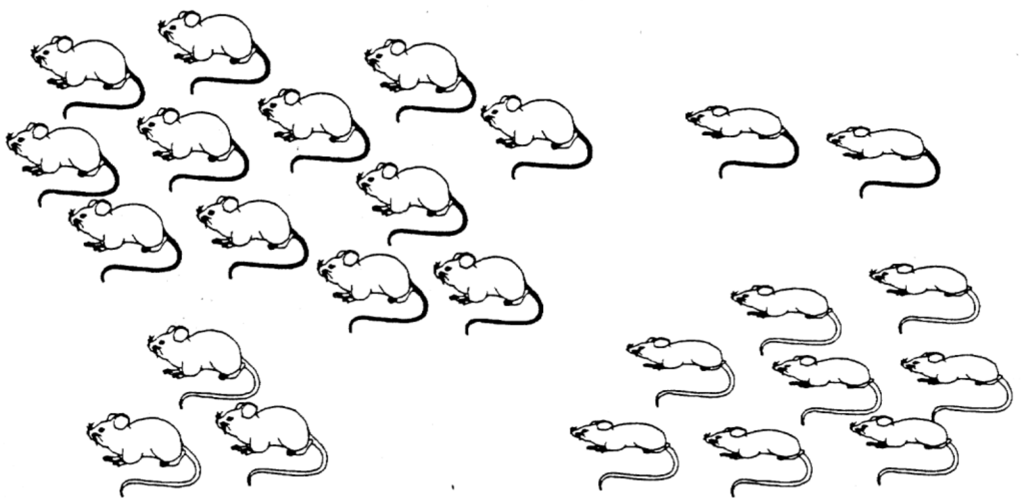
What are the chances that the piece is a red round or blue round piece?

a. cannot be determined
b. 1 chance out of 3
c. 1 chance out of 21
d. 15 chances out of 21
e. 1 chance out of 2

18. *because*

a. 1 of the 2 shapes is round.
b. 15 of the 21 pieces are red or blue.
c. there is no way to tell which piece will be picked.
d. only 1 of the 21 pieces is picked out of the bag.
e. 1 of every 3 pieces is a red or blue round piece.

19. Farmer Brown was observing the mice that live in his field. He discovered that all of them were either fat or thin. Also, all of them had either black tails or white tails. This made him wonder if there might be a link between the size of the mice and the



color of their tails. So, he captured all of the mice in one part of his field and observed them. Below are the mice that he captured.

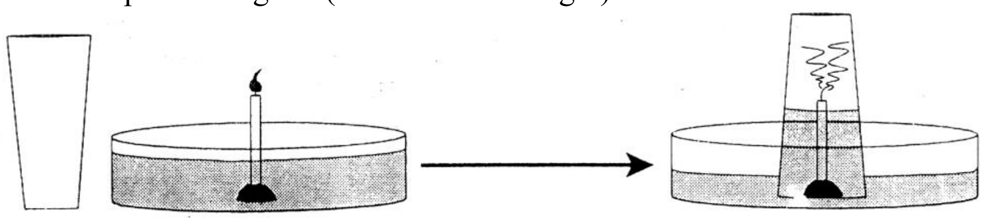
Do you think there is a link between the size of the mice and the color of their tails?

a. appears to be a link
b. appears not to be a link
c. cannot make a reasonable guess

20. *because*

a. there are some of each kind of mouse.
b. there may be a genetic link between mouse size and tail color.
c. there were not enough mice captured.
d. most of the fat mice have black tails while most of the thin mice have white tails.
e. as the mice grew fatter, their tails became darker.

21. The figure below at the left shows a drinking glass and a burning birthday candle stuck in a small piece of clay standing in a pan of water. When the glass is turned upside down, put over the candle, and placed in the water, the candle quickly goes out and water rushes up into the glass (as shown at the right).



This observation raises an interesting question: Why does the water rush up into the glass?

Here is a possible explanation. The flame converts oxygen into carbon dioxide. Because oxygen does not dissolve rapidly into water but carbon dioxide does, the newly formed carbon dioxide dissolves rapidly into the water, lowering the air pressure inside the glass.

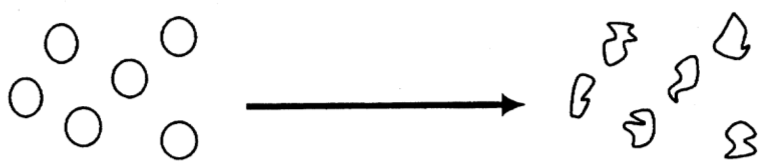
Suppose you have the materials mentioned above plus some matches and some dry ice (dry ice is frozen carbon dioxide). *Using some or all of the materials, how could you test this possible explanation?*

a. Saturate the water with carbon dioxide and redo the experiment, noting the amount of water rise.
b. The water rises because oxygen is consumed, so redo the experiment in exactly the same way to show water rise due to oxygen loss.
c. Conduct a controlled experiment, varying only the number of candles to see if that makes a difference.
d. Suction is responsible for the water rise, so put a balloon over the top of an open-ended cylinder and place the cylinder over the burning candle.
e. Redo the experiment, but make sure it is controlled by holding all independent variables constant; then measure the amount of water rise.

22. What result of your test (mentioned in #21 above) would show that your explanation is probably wrong?

a. The water rises the same as it did before.
b. The water rises less than it did before.
c. The balloon expands out.
d. The balloon is sucked in.

23. A student put a drop of blood on a microscope slide and then looked at the blood under a microscope. As you can see in the diagram below, the magnified red blood cells look like little round balls. After adding a few drops of salt water to the drop of blood, the student noticed that the cells appeared to become smaller.



Magnified Red Blood Cells — After Adding Salt Water

This observation raises an interesting question: Why do the red blood cells appear smaller?

Here are two possible explanations: I. Salt ions (Na+ and Cl-) push on the cell membranes and make the cells appear smaller. II. Water molecules are attracted to the salt ions so the water molecules move out of the cells and leave the cells smaller.

To test these explanations, the student used some salt water, a very accurate weighing device, and some water-filled plastic bags, and assumed the plastic behaves just like red- blood-cell membranes. The experiment involved carefully weighing a water-filled bag, placing it in a salt solution for ten minutes and then reweighing the bag.

What result of the experiment would best show that explanation I is probably wrong?

a. the bag loses weight
b. the bag weighs the same
c. the bag appears smaller

24. *What result of the experiment would best show that explanation II is probably wrong?*

a. the bag loses weight
b. the bag weighs the same
c. the bag appears smaller