CHAPTER I
INTRODUCTION

1.1 Background

In 2015, The World Economic Forum report that there are 16 skills needed for human to face the 21st century challenges, two of which are scientific literacy (Anto, Hasruddin & Gultom, 2022) and creativity (Altan and S. Tan, 2020; Miller & Dumford, 2016). Entering the 21st century, humans are required to have high quality in the era of industrialization and globalization (Winarni, Karpudewa, Karyadi & Gumono, 2022). Education hold the important aspect in preparing high-quality of human resources. As part of education, science education also has the important role to producing human resource which has the qualities needed by humans in the 21st century especially in the field of science and technology. By developing scientific literacy and creativity in the process of learning, students can have meaningful learning in science education. Scientific literacy is important skill to develop because it has the competence of read, write, and communicate science topics and socio-scientific issues relevant to culture and students' understanding in everyday life and understanding the processes for developing new knowledge in the fields of science and technology to solving daily problem (Greenhow et al., 2015 in Wahyu, Suastra, Sadia & Suarni, 2020).

There is general agreement around the world that one of the measures of educational quality is seen from the increase of scientific literacy (Permanasari, 2016 in Anto et al., 2022). Programme for International Students Assessment (PISA) is one of the Organisation for Economic Co-operation and Development (OECD) program that evaluates the skills and knowledge of 15-year-old participating country students every three year since the year 2000. Unfortunately, in 2018 Indonesia was ranked 70th in science category out of 78th countries (OECD, 2019 in Winarni et al., 2022) which indicates that Indonesia still in low position from the international average PISA score. PISA 2018 results show that the OECD has an average science score of 498, while Indonesia scored a very low 396 categories proves that the quality of education in Indonesia is still lacking (Anto et al., 2022).

There are several factors that can influence the quality of education, namely internal and external factors. Internal factors arise from the child himself, such as health, mind, intelligence, student motivation, participation in the learning process, organization of the learning process, and relationship between students and teaching. External factors are those that come from outside the child, such as family, community, friends, teachers, media, facilities, and environmental infrastructure (Taurina, 2015; Wijaya & Bukhori, 2015; Widodo, 2016 in Jufrida et al., 2019). The low scientific literacy ability of Indonesian students is generally caused by the external factor which is learning activities that are not yet oriented to the development of scientific literacy (Sutrisna, 2021). Indonesian teachers still trapped in teacher-centered learning with students only memorizing science concept without relates it to the problem that students might encountered in their daily life. The lack of scientific literacy in Indonesia mostly reflects the inability of Indonesian students to analyze and apply concepts to solve problems. This has an impact on low student science learning achievement (Jufrida et al., 2019).

Sulistiyowati, Abdurrahman & Jalmo (2018) in their paper, stated that one of the learning innovations that teachers can use is the STEM approach in learning to train the science literacy. A STEM learning approach is a learning approach that can upskill and prepare high-quality human resources (HR) according to the skill requirements of the 21st century (Jang, 2016 in Anto et al., 2022). STEM brings together four elements by focusing on solving real problems in everyday life (Erduran, 2020 in Winarni et al., 2022). Integrated STEM education is learning that uses science, technology, engineering, and mathematics in real-world contexts to develop STEM competencies that enable learners to compete in the new economic era (Tsupros, Kohler & Hallinen, 2009 in Sulistiyowati et al., 2018). One approach to grow more integrated STEM learning is through engineering experiences housed in real-world contexts that leverage concept from mathematics, science, and technology (English, 2015). The important aspect of engineering is the development of design process (English et al., 2017). In 2013, Next Generation Science Standard released a statement regarding the need integration between science

and engineering. Science teachers are expected to delivering science concept using scientific and engineering practices (Guzey, Moore & Harwell, 2016).

STEM Engineering Design Process model is recognized as a general model of the creative process that can be applied to STEM courses (Householder & Hailey, 2012 in Siew, 2017). Creativity according to Amabile (2012) in Hanif et al. (2019) is the ability to create an original product or solution to open-ended task. EDP is one of the STEM branch that encourages students to learn from failure with the engineering step to find a solution of a problem. Nevertheless, one of the fundamental concepts of real-world engineering is that there is no one right solution to a problem. Instead, it is a process and mindset for engineers to develop their own creative solutions to problems (Veety et al., 2018). In this respect, engineering design process can develop students' creativity. This concept of engineering design process is in line with Berland et al., (2014) quoted from National Academy of Engineers & National Research Council (2009); National Research Council (2012) that problem will have multiple possible solutions and it is the engineers that must generate multiple solutions until develop a system to choose the best solution. By this response, creativity has the important role in engineering process not only for making creative product but also in developing various solutions of a problem.

Based on the Kozbelt et al. (2010), there is an alliterative framework that is frequently used in the study of creativity named "Four P's". They are: Person, Process, Product, and Press/Place. The "person" component relates to research into the psychological traits and behavioral features associated with creative people, while the "process" component refers to the numerous cognitive processes involved in creative performance. The "product" component focuses on evaluating creative products and attempting to find more precise features that result in this creative classification. Finally, the "press" component focuses on how an individual's surroundings can affect creative functioning. Those components of creativity are can't be separated. However, most of the creative process are measured based on actual creative outputs which is the basic feature of most divergent thinking tests (Torrance, 1998;

Wallach & Kogan, 1965 in Miller, 2014). While the creative process measurement is lacking in the availability. Therefore, Miller (2014) in her study develop an instrument that can be use to measure creative process consist of six sub scales such as idea manipulation, imagery/sensory, flow, metaphorical/analogical thinking, idea generation, and incubation. Creativity is indeed an important factor in all of the engineering design process (Zheng, Ritter & Miller, 2018).

The most famous step of engineering design process model among science and engineer educators is Massachusetts Department of Education Engineering Design Process Model (Massachusetts DOE, 2006). Even in one of the study from Veety, Sur & Eliott (2018), the steps of engineering design process that most teacher choose is similar with Massachusetts Department of Education Engineering Design Process Model (Massachusetts DOE, 2006) which then called into easier abbreviated name as DEAL (determine the problem, evaluate possible solutions, apply the best solution, look back and reflect). From this model, another model also developed such as DIGIER model from Han & Shim (2019) with the steps are defining the problem, ingathering information, generating the solution, implementing the best solution, evaluating the solution and reflecting. Other models are presented by (Hammack et al. 2015; Berland et al. 2014; Bampasidis et al. 2021; Alemdar et al. 2018; English et al. 2017; Nurtanto et al. 2020; Park et al. 2018; Shahali et al. 2017; Altan et al. 2021; Zhou et al. 2017; Siew, 2017; Baydere & Bodur, 2022). However, the main step in engineering design process which all the various model from those researchers are defining the problem well, making various solutions, choose the best solution, implementing the solution by making a product, and communicate the result to evaluate the product.

The previous research which shows that the engineering design process has a good impact in science learning conducted by Hammack et al., (2015) it can improve students' understanding of technology, chemical engineering content, and attitudes towards engineering. Bampasidis et al. (2021) also report the positive effect of engineering design process in students' attitudes, performance, and transversal skills. STEM education also has a good impact in

students' scientific literacy as stated by Şimşek and Hamzaoğlu (2023) that when context-based STEM activies were implemented in experiment class, positive impact on scientific literacy and STEM motivation was higher than in control class. Another study come in the field of Biology form Safitri and Tanjung (2023) that developed STEM-based student's worksheet on virus material is effective to improve scientific literacy. Another study that had done in investigate students' scientific literacy was conducted by Rahman (2023) in environmental pollution materials by implementing inquiry-learning model with STEM approach with the conclusion that the implementation can be able to improve students' scientific literacy. The study in elementary school students already done too. Marsari & Rifma (2023) developing STEM-based teaching materials to improve students' scientific literacy and the result is proven positive. From those relating research of scientific literacy in STEM education, the study of scientific literacy in STEM engineering design process is still lacking. One study that is similar with this research was conducted by Baydere & Bodur (2022) in 9^{th} grade students by implementing engineering design in designing an incubator (topic) to help them develop STEM literacy. The difference with present research is in the project and materials. This research also conduct in 9^{th} grade students by implementing engineering design to enhance scientific literacy but in element, compound, and mixture topic with water filtration tool as a project.

The researcher choose the topic of element, compound, and mixture is because in the sub topic of mixture, there is a discussion about separating mixture. And one of the project in separating mixture is one of the solution that needed in real life which is water filtration tool. Based on this reason, the topic will be related in students' daily life and able to challenge students to solve the real problem. The research in making water filtration was done by Usta and Ültay (2022). The research purposed to know the opinions from fourth-grade students regarding augmented reality and animation-supported STEM activities on the "Water Treatment" topic. The result shows that students are enjoy engaging with the learning activity using animation-supported STEM and it is appropriate to be implemented in the learning process. Another study

that is similar with this study is conducted by Aydın and Karslı (2019). They were using 7th grade students as their research sample. The aims of their study was to determine students' view on engineering design process in separating mixture topic. Their study was use qualitative research approach while this study using quantitative research approach. They were conducting the research in 7th grade, unlike this study that conduct in 9th grade. Another factor that distinguishes this research from previous research is the treatment performed when measuring the feasibility of a water filtration. The purified water produces by water filtration tool in this research is measured by pH indicator and turbidity meter.

The previous research of creativity in STEM education is already done by many researchers such as (Altan and Tan, 2020) examine the concepts of creativity in the Design Based Learning and to determine the students' perceptions of this step. Investigate the effect of STEM applications designed for the atomic system and periodic system unit on the scientific creativity of 9th-grade students (Eroglu & Bektas, 2022). Based on Siew, Goh & Sulaiman (2016) STEM-EDP can fostering students' creativity, problem solving skills, and thinking skills among rural secondary. Huang, Chang and Chou (2020) analyzed the effects of creative thinking, psychomotor skills, and creative self-efficacy (CSE) on the engineering design creativity. Avsec and Savec (2019) examine the role of interdisciplinary augmentation is able to enhance students' creativity synergy with critical thinking. The research conduct a critical case study of engineering pedagogy showed that one of the aspect of creativity, convergent thinking, was well represented in engineering course (Daly, Mosyjowski & Seifert 2014). While in Miller et al. (2021), compare and contrast social science and engineering approaches using design ratings of nearly 1000 engineering design ideas. From all the previous studies that already stated, only study from Conradty and Bogner (2018) that quantifying individual creativity using the same instrument as present research of creativity, which is CPAC (Cognitive Processes Associated with Creativity) by Miller (2014). However, the study only use 10 items of questionnaire in the form of Likert scale with ranges from 1 up to 4. While in this research, CPAC questionnaire

that used is 28 items with Likert scale ranges from 1 up to 5. And also in the previous study, the implementation is not STEM engineering design process and not in the same topic.

The study of STEM engineering design process already done to investigate the students' scientific literacy and creativity. Nevertheless, the research in STEM engineering design process in enhancing students' scientific literacy and creativity in element, compound, and mixture topic with further treatment in testing purified water and using CPAC to assess students' creativity has not been done. That is why this research will investigate the effect of engineering design process on students' scientific literacy and creativity in element, compound, and mixture topic.

1.2 Research Problem

This study generate the research problem as "How does the effect of STEM-Engineering Design Process in students' scientific literacy and creativity in element, compound, and mixture topic?" From this research problem, this research will investigate the following questions:

1) How does the effect of STEM-Engineering Design Process towards students' scientific literacy in element, compound, and mixture topic?
2) How does the effect of STEM-Engineering Design Process towards students' creativity in element, compound, and mixture topic?

1.3 Research Objective

Based on the research questions that already stated above, the objectives of this research are shown as follow:

1) To investigate the effect of STEM-Engineering Design Process toward students' scientific literacy in element, compound, and mixture topic.
2) To investigate the effect of STEM-Engineering Design Process toward students' creativity in element, compound, and mixture topic.

1.4 Research Benefit

1) For students, they can enhance their scientific literacy as well as their creativity using stem engineering design process. The field of science requires students understanding of acids and bases concept that related to water quality and the density concept that related to water filtration. The

field of technology requires students to find out information about how to design and develop the water filtration system. The field of engineering requires students to design an effective and efficient water filtration system. The field of mathematics requires students to carry out calculations related to the design of a water filtration system (Ridlo et al., 2020).

2) For teacher, stem engineering design process can be the innovation in learning activity to build an active learning and train students' scientific literacy while also improve students' creativity.
3) For other researchers, this paper expected to be a guide to do the research in stem engineering design process by looking for another project, another dependent variable, and increasing the sample size.

1.5 Operational Definition

1) Scientific Literacy

PISA defined scientific literacy as the ability of optimizing scientific knowledge, identify question and draw conclusions based on the evidence in order to comprehend and participate in decisions regarding the natural world and the changes brought about by human activities. Scientific literacy is the dependent variable of this research which the result depends on the implementation of the STEM-EDP approach in learning element, compound, and mixture topic. The instrument is 20 multiple choice objective test develop by the researcher. Scientific literacy objective test was develop based on competency and knowledge aspect from OECD (2019). The competency aspect consists of explain phenomena scientifically, design and evaluate scientific enquiry, and interpret the data and evidence scientifically. While the knowledge aspect consists of content knowledge, procedural knowledge, and epistemic knowledge. The data is taken twice as pre-test and post-test.

2) Creativity

Guilford (1950) in Conradty and Bogner (2018) defined creativity as the new, original, unique, and effective method to solving problems. Students' creativity is the dependent variable of this research which the result depends on the implementation of the STEM-EDP approach in

learning Element, Compound, and Mixture topic. The instrument that used to collect the data is 28 Likert scale questionnaire items of CPAC from Miller (2014) which consists of six sub scales, idea manipulation, imagery/sensory, flow, metaphorical/analogical, idea generation, and incubation. The scale ranges from (1) never; (2) Rarely; (3) Sometimes; (4) Often; (5) Always. The data is taken twice as pre-test and post-test.

3) STEM-Engineering Design Process

Engineering Design Process which then abbreviated become EDP is a sequence step that connecting science and mathematics in solving problem, developing creative thinking, formulating solutions and making decisions, and taking into account alternate strategies to address certain constraints (Samsudin et al., 2007; Wang et al., 2011; Yasin et al., 2012 in Shahali et al., 2016). The EDP is the research's independent variable that is used in the classroom. The step of STEM-EDP in this research is adapted from Han and Shim (2019) which consists of defining the problem, ingathering information, generating the solution, implementing the best solution, and evaluating the solution and reflecting. There will be a worksheet and lesson plan to ensure the students implementing EDP in their learning process.

1.6 Organization of Research Paper

The research structured based on the guidelines for writing research paper from Universitas Pendidikan Indonesia 2019 edition. The arrangement of each chapter is shown below:

1) Chapter I: Introduction

This chapter consists of background, research problem, research objective, research benefit, organization of research paper, and limitation of problem.

2) Chapter II: Literature Review

This chapter discuss detail theory of the research. The theories discuss in this research are engineering design process, students' scientific literacy, students' creativity, and element, compound, and mixture topic. This chapter also discussed the relevant research of the research theories.

3) Chapter III: Research Method

   This chapter consists of research method, research design, subject of research including sample and population, research instrument that use to collect the data, data analysis and research procedure.

4) Chapter IV: Results and Discussions

   This chapter discuss the research finding and explain the factors that can influence the results. In this chapter, research question and hypothesis supposed to be answered.

5) Chapter V: Conclusion, Implication, and Recommendation

   This chapter examine the conclusion of the result that already analyzed in the previous research. The implication discuss about how the treatment was implemented during the research. And the recommendation for the future research.

1.7 Limitation of Problem

1) Scientific literacy in PISA 2018 is defined by the three competencies which are explaining phenomena scientifically, evaluating and designing scientific enquiry, and interpreting data and evidence scientifically (OECD, 2019). These competencies require knowledge aspect such as content, procedural, and epistemic. Therefore, this research limited by the competency and knowledge aspects of scientific literacy.
2) Creativity in this research is limited in the cognitive process consists of six sub scales which are idea manipulation, imagery/sensory, flow, metaphorical/analogical thinking, idea generation, and incubation (Miller, 2014).
3) The topic in this research is limited by the learning objective in Sub Chapter 5.3 in the Element, Compound, and Mixture topic, which were designed by the Indonesia Ministry of Education in Independent Curriculum. The project is focus on the concept of the separating mixture in topic of element, compound, and mixture. Students will use their ability to design water filtration tool during the engineering design process. Students investigate turbidity and pH of purified water produced from their water filtration tool.