Didaktika: Jurnal Kependidikan, Vol. 13, No. 2, Mei 2024

Enhancing Students' Nature of Science Using STEM Engineering Design Process in Elements, Compounds, and Mixtures Topic

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Abstract

A scientifically educated culture is the ultimate goal of science education worldwide, and one of the key elements in acquiring scientific literacy is comprehending the nature of science (NOS). This study aimed to enhance the views of Junior High School students of nature of science (NOS) in Elements, Compounds, and Mixtures Topic using the STEM engineering design process. The method applied in this research is quasi-experiment. The sampling technique used was convenience sampling, which was taken from grade 9 in one of the junior high schools in Bandung, Jawa Barat, Indonesia, with the age range 14-15 years old. The sample consisted of 38 students in total, consisting of the experimental class (n=19 students) and control class (n=19 students). The experimental class is taught using the STEM engineering design process, while the control class is conducted using conventional learning. The result of this research was that the N-gain students' Nature of Science of experiment class shows the number of 0.4051, which is categorized as moderate improvement, whereas the control class shows the number of 0.0151, which is categorized as low improvement. The hypothesis test using an independent sample t-test for Nature of science shows that there is a difference between the experimental class and control class, where the experimental class gain higher achievement in each NOS issues in the questionaire. Based on this research, the STEM engineering design process could be considered to an alternative to improve students' nature of science. This research has the potential to significantly impact scientific education by motivating science teachers to include the core ideas of NOS and STEM-EDP into the curriculum for junior high school students.

Keywords: *Scientific literacy, Nature of science, STEM Engineering design process*

Introduction

The development of adequate student conceptions of the nature of science has been a perennial objective of science instruction regardless of the currently advocated pedagogical or curricular emphases (Lederman, 1992). The goal of science education worldwide is to achieve a scientifically literate society, and one of the important components in developing scientific literacy is understanding the nature of science (NOS) (Rahayu, 2020). Indeed, helping students develop an adequate understanding of NOS is 'one of the most commonly stated objectives for science education (Kimball, 1967).

NOS refers to the epistemology and sociology of science, science as a way of knowing, or the values and beliefs inherent to scientific knowledge and its development (Lederman, 1992). If students understand NOS, it will give them science skills (Almiasih & Winarto, 2022). NOS is the part that is concerned with understanding the nature of scientific science as a whole, meaning that it is not only focused on understanding the concepts presented but rather on understanding aspects of NOS itself which includes the empirical, creative and imaginative nature of science, as well as embedding socio-cultural and tentative nature (Almiasih & Winarto, 2022; Lestari & Rahmawati, 2020; Tursinawati & Widodo, 2019). Although NOS has been considered important in science education and NOS topics are introduced at the beginning of a textbook, lessons, and subject matters then continue with science content, the extensive misunderstandings about NOS aspects in the textbooks and students' minds still exist (Mccomas, 2017). Moreover, prospective teachers, and educators do not have sophisticated views of NOS (Irez, 2006). Majority of these studies have been conducted with ordinary prospective teachers and teachers and rarely with students. Therefore, problems about NOS understandings of different groups of students who are in current educational system are not clear. According to the previous research by Habiby, I., & Suwandi, T. (2020) reported the findings demonstrated that students' comprehension of NOS is still lacking. The minimal percentage of well-informed perspectives across all aspects of the NOS assessed, encompassing both likert-scale items and open-ended replies, signifies a limited comprehension of NOS among the students (Habiby & Suwandi, 2020).

To address this issue, it is necessary to examine the curriculum papers referring to Indonesia. The Minister of Education and Culture Regulation number 20 year 2016. An annex is provided detailing Competency Standards for Primary and Secondary Education Graduates in Indonesia, focusing on the knowledge dimension for junior high school students. Having factual, conceptual, procedural, and metacognitive knowledge at a simple technical and specific level regarding with: (1) science, (2) technology, (3) art, and (4) culture. Able to link the knowledge in the context of themself, family, school, community, and the surrounding environment, nation, country, and regional sector (Permendikbud, 2016). According to the provisions of the Permendikbud regulation, scientific education in Indonesia has shifted its pedagogical goals toward science literacy. Nonetheless, reality indicates that Indonesian pupils' scientific literacy levels remain poor. According to the PISA 2009-2015 results, Indonesian students' scientific literacy is inadequate. Indonesian students' average success score in scientific literacy is lower than the OECD average (Wati et al., 2017). Furthermore, there was a reduction in scientific literacy achievement at PISA 2022, with a score of 359 compared to the OECD average of 489 (OECD, 2023). The poor level of scientific literacy accomplishment is most likely attributable to pupils' lack of grasp of the nature of science (NOS). The essence of scientific literacy is connected to the comprehension of Nature of Science (Khishfe & Lederman, 2007). Student characteristics that have scientific literacy are directly related to the NOS components (Akerson et al., 2019; Khishfe, 2017).

Previous research in various countries measured students' understanding of NOS at the high-grade level and on a large scale (Das et al., 2019; Dogan & Abd-El-Khalick, 2008). In this research, it is known that most students have an inadequate understanding of NOS. On the other hand, research that improves students' understanding of NOS shows that NOS understanding will help the acquisition of scientific content (Michel & Neumann, 2016), decision-making on socioscientific issues (Khishfe, 2012), and making better arguments (Khishfe, 2014; Khishfe et al., 2017). If students understand NOS, it will give them skills in science (Almiasih & Winarto, 2022). This implies that pupils' other skills will improve with sufficient comprehension of NOS. Research on Indonesian students' comprehension of NOS is still in its early stages. Furthermore, the outcomes of NOS understanding analyses have not been widely documented in terms of follow-up and implications in learning science.

STEM learning, denoting the interdisciplinary integration of science, technology, engineering, and mathematics, has been recognized as a pedagogical approach to fostering students' critical thinking and problem-solving skills (Asunda, 2014). Through STEM learning, it is hoped that students can understand and discover real-world problems and natural phenomena and be skilled in drawing conclusions and decisions based on facts and data (CNA Tarte, 2022). The study conducted in 2023 demonstrates that the STEM-based student worksheet focusing on virus material is an excellent tool for enhancing scientific literacy (Safitri & Tanjung, 2023). STEM learning significantly enhances students’ science process kills and attitudes toward inquiry instruction (Setiawaty et al., 2018). previous research have created STEM-focused educational resources to enhance students' scientific literacy, and the outcomes have been empirically demonstrated to be beneficial (Marsari & Rifma, 2023). STEM is the right learning approach to improve the learning processes' quality and outcomes comprehensively (Yuanita & Kurnia, 2019). The STEM approach is one of the learning innovations instructors can employ to develop science literacy (Sudarsono et al., 2020; Sulistiyowati et al., 2018).

The STEM Engineering Design Process model is recognized as a general creative process model that can be applied to STEM courses (Hailey, 2012; Siew, 2017). The Engineering Design Process (EDP) is a sequential series of steps that integrates science and mathematics to solve problems, foster creative thinking, formulate solutions, make decisions, and consider alternative strategies to overcome constraints (Unlu et al., 2016; Wang et al., 2011; Wĭnarno et al., 2020; Yasin et al., 2012). The EDP, which stands for Engineering Design Process, serves as the independent variable in classroom research. The STEM-EDP step utilized in this research is derived from Han & Shim (2019), encompassing the following stages: problem definition, information collection, solution planning, implementation of the solution, testing the solution, and evaluation of the solution together with reflection. This model consists of activities designed to help students develop creative solutions methodologically using the engineering design process to solve problems in everyday life (Han & Shim, 2019).

The previous research shows that the engineering design process positively impacts science learning and improves students’ understanding of technology, chemical engineering content, and attitudes toward engineering (Hammack et al., 2015). Another research investigates the effect of STEM applications designed for the atomic system and periodic system unit on the scientific creativity of 9th-grade students (Eroğlu & Bektaş, 2022). Based on Siew et al. (2016), STEM-EDP can foster students’ creativity, problem-solving skills, and thinking skills in rural secondary. STEM-EDP aims to empower students with a versatile and adaptive skill set for upcoming challenges (Siew et al., 2016). A research study in 2020 analyzed the effects of creative thinking, psychomotor skills, and creative self-efficacy (CSE) on engineering design creativity (Huang et al., 2020). The study in elementary school students is already done too. Research by Ilmi et al. (2021) indicates that utilizing STEM-EDP learning might enhance student learning results, impacting fifth-grade students' topic learning outcomes at SD 10 Pulau Punjung (Ilmi et al., 2021). Another study in the same year reports the beneficial impact of the engineering design process on students' attitudes, performance, and transversal abilities. However, there is no study on applying STEM-EDP to enhance junior high school students' comprehension of the Nature of Science (Bampasidis et al., 2021). Things that have been mentioned given this circumstance, it was thought important to conduct study on students' knowledge of NOS using the STEM engineering design process.

This study aimed at enhancing the views of Junior High School students of nature of science (NOS) in Indonesia using the STEM engineering process, tambahakan kalimatnya, tambahkan terkait dengan lebih focus pada aspeknya dll. The instrument discussed in this study is the Views on Science and Education (VOSE) instrument by Chen, S. (2006), which has not been previously applied to Indonesian secondary school students, making it a pioneering endeavor. Notably, the research design incorporates both a control class and an experiment class, which enhances the study's methodology beyond a mere questionnaire-based approach. Additionally, the instrument incorporates specific criteria related to the Nature of Science (NOS), such as the inclusion of tentative aspects and scientific literacy. This specificity adds depth and relevance to the study.

The findings of this research have the potential to greatly influence science education by encouraging science teachers to implement the fundamental principles of NOS and STEM-EDP among junior high school students. This study aimed to enhance the views of Junior High School students on the nature of science (NOS) in Elements, Compounds, and Mixtures Topic using the STEM engineering design process".

Method

Research Design

The research method used in this research in Quasi Experiment. The Researcher assigned two groups of participants. One group was the control group, while the other was the experimental group. Both groups will take pre-test and post-test, but only the experimental group will conduct a treatment (Creswell & Clark, 2018). The experimental group uses the STEM-engineering design process. In contrast, the control group used conventional learning with the same project in both classes. The researcher administered a pre-test to both groups, conducted experimental treatment activities only for the experimental group, and then administered a post-test to assess the differences between the two groups. According to Creswell, the basic intent of an experimental design is to test the impact of a treatment (or an intervention) on an outcome, controlling for all other factors that might influence that outcome (Creswell & Clark, 2018). Therefore, the research design compares the pretest results to determine their prior knowledge and after giving the treatment of the final post-test, as shown in Table 1.

Table 1. Research Design

	O1	X	O2
Control Group	Pre-test	Conventional Learning	Post-test
Experiment Group	Pre-Test	STEM engineering design process	Post-test

Participant

The characteristic of the selected schools is that they have implemented the 2013 National Curriculum in the learning process. Data was obtained in the second semester of the 2022/2023 academic year. The location where this research was carried out is in Bandung City, Indonesia. Population is a set of units that possess variable characteristics under observation and for which findings of studies may be generalized (Shukla et al., 2020). 9th-grade students were the population of this study, and 38 students from School X were used as the sample, with the age range 14-15 years old. The selected participants are chosen because they are available to be studied. There are 38 students separated into 2 classes: control group and experiment group. The distribution of participants is shown in Table 2.

It is important to note that you do not need to use too many formulas or tables unless it is absolutely necessary to be displayed.

Table 2. Participant Distribution

	Number of students	Percentage
Control Group	19	50%
Experiment Group	19	50%
Total	38	100%

Research Instrument

In this research, the understanding of NOS was measured based on the Views on Science and Education (VOSE) instrument by Chen, S. (2006). VOSE is an empirically based instrument that can determine subjects' conceptions and attitudes toward teaching NOS. This dual function is an innovation in assessment tools for NOS research (Chen, 2006). For language differences, the instrument was translated from English into Bahasa Indonesia. There are 15 questions in the questionnaire, and each one is followed by a number of items that represent various philosophical perspectives. Each item is rated by participants on a five-point Likert scale. Likert-Scale makes it easy to read the participant's perspective (Taherdoost, 2019). Participants are instructed to read the whole set of items before rating their opinion of each item on a five-point scale, i.e., strongly disagree, disagree, uncertain/no comment, agree, and strongly agree.

The instrument utilized in this study comprises seven distinct issues, namely: 1) Tentativeness, 2) Nature of Observations, 3) Scientific Methods, 4) Theories and Laws, 5) Use of Imagination, 6) Validation of Scientific Knowledge, and 7) Subjectivity and Objectivity. Each of these issues encompasses specific positions and question items designed to capture various aspects of students' understanding of the nature of science.

Research Procedure

There are three main procedures in this research: the preparation stage, implementation stage, and completion stage. The preparation stage involves defining the research problem. Afterward, researched literature on numerous representations of the engineering design process of the Nature of Science (NOS) from diverse perspectives and searched for validated instruments. For the implementation stage, researchers conduct pre-test, treatments, and post-tests after the treatments. The control group used conventional learning methods for the treatments. The learning phases used in the control class is depicted in figure 1.

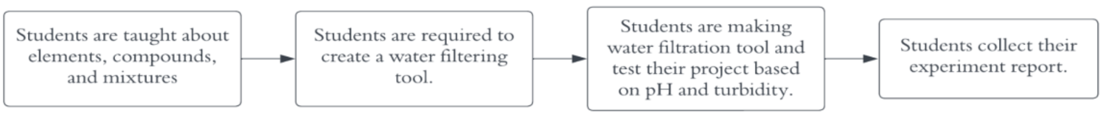

Figure 1. The flowchart of learning phases used in the control class

Meanwhile, the experiment class were given STEM-EDP learning model with the same project (water filtration tools). The syntactical framework of the STEM-Engineering Design process, as developed by Han & Shim, (2019) namely DIGIER model. This model consists of activities designed to help students develop creative solutions methodologically using the engineering design process to solve problems in everyday life (Han & Shim, 2019). This representation serves as a comprehensive reference for understanding the sequential phases and components involved in the STEM-Engineering Design process used in the research. The implementation of DIGIER model has been systematically organized in Table 3.

Table 3. Syntax of STEM Engineering Design Process

Phases	Behavior	Activities
Define the problem	a. Recognizing the problematic situation. b. Recognizing the need for problem-solving. c. Specific clarification of the problem to be solved.	a. Students are given the problem and asked to make a solution based on the problem given. b. Students define the problem by understanding the material about elements, compounds, and mixtures.
Ingathering information	a. Ghaterhing information related to the problem by taking advantage of diverse sources.	a. Students look for various sources to solve the problem.

	b. Organizing information by checking the relation between the problem and information	
Generating the solution	a. Generating various solutions. b. Refining their solutions. c. Making a presentation and evaluating by the group. d. Generating a solution by the group based on evaluation results. e. Elaborating the solution by the group.	a. Students generate various possible solutions and choose the best solution. b. Students present their initial design based on the implementation of the best solution that they decided. c. Students present and discuss their solution to get an evaluation of their solution. d. Students make the new design based on the evaluation results and then elaborate on the final solution.
Implementing the best solution	a. Making a prototype based on the group's solution. b. Arranging the prototype's characteristics.	a. Students are making the prototype of their tool. b. Students Categorize the characteristics based on their importance and relevance to the overall solution.
Evaluating the solution and reflecting	a. Presenting and evaluating of the prototype's characteristics by the group. b. Finding improvement measures for the prototype's drawbacks. c. Generating a new solution.	a. Students present their prototype of water filtration and evaluate the tool (testing the tool based on pH and turbidity) then make final design based on their evaluation. b. The students then redesign their water filtration tools based on the evaluations they obtained and find improvements by testing the tools based on pH and turbidity. c. Students generate the final solution based on their experience. d. Students then make a report and collect their report. e. Students conclude the learning activities that they had done.

In the final stage of the research procedure, the researchers collect and calculate the data for additional analysis to obtain the results. Based on the findings, researchers will proceed to conclude.

Data Analysis

For the data analysis, each item which has been rated by participants on a five-point Likert scale i.e., strongly disagree, disagree, uncertain/no comment, agree, and strongly agree, is converted into a percentage. In statistics, normality tests are used to determine if a data set is well modelled by a normal distribution and to compute how likely it is for a random variable underlying the data set to be normally distributed (Mohd Razali & Bee Wah, 2011). In this research, normality was analyzed to know whether the experimental and control group data are distributed normally. If both data are distributed normally, the next step is to test the data using an independent t-test. While, if the data distribution was not normal, the data analysis can use the Whitney Test. In this research, all of the data was calculated using SPPS Statistics.

Results

Students' Views on Science and Education (VOSE)

In this research, Students' nature of science (NOS) is determined by giving all students both in experimental class and control class the views on science and education (VOSE) questionnaire in pre-test and post-test. The average score of the pre-test in both classes is around 63.68 and 63.58 and for post-test both classes get average scores 80.21 and 64.68. The comparison of both results can be seen in figure 2.

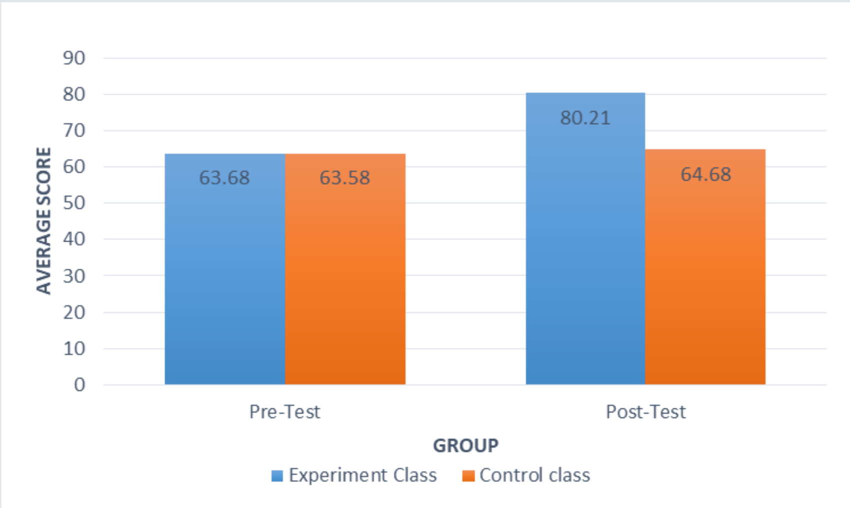

Figure 2. The Average Score of Both Pre-test and Post-test of VOSE Test Result of Control and Experiment Class8l

Based on Figure 2, it clearly shown that the mean of post-test is higher that pre-test in both classes. In the experiment class, the score difference between post-test and pre-test is 5.69, while for the control class, the gap between the post-test and pre-test is 1.16. This shown that the gain score for the experiment class is higher than control class. The Control and Experiment Class's Peroration of Students' Views on Science and Education (VOSE) Test Results shown in table 4 below.

Table 4. The Peroration of Students' Views on Science and Education (VOSE) Test Result of Control and Experiment Class

Descriptive Statictics					
	N	Minimum	Maximum	Mean	Std.Dev
Pre-test Experiment	19	58	69	63.68	3.233
Post-test Experiment	19	75	89	80.21	3.119
Pre-test Control	19	54	71	63.58	4.141
Post-test Control	19	54	75	64.68	5.175
Valid N	19				

In advance of doing a hypothesis test, preliminary tests such as normality and homogeneity are conducted using IBM Statistical SPSS 26 to see if the study data can be parametrically assessed. The normality of the pre-test and post-test data in both the experiment and control classes was evaluated using the Shapiro-Wilk test, as shown in Table 5.

Table 5. Normality and homogeneity test with Saphiro-Wilk

Component	**Pre-test**		**Post-test**	
	Experiment Class	**Control Class**	**Experiment Class**	**Control Class**
Normality Test				
Signification Sig α > 0.05	0.517	0.801	0.120	0.955
Information	Normally Distributed	Normally Distributed	Normally Distributed	Normally Distributed
Homogenity Test				
Signification Sig α > 0.05	0.559		0.748	
Information	Both data are homogen		Both data are homogen	

The significant values (Sig.) obtained for the normality tests were 0.517 and 0.801 for the pre-test in the experiment and control classes, respectively. In the post-test, the Sig. values were 0.120 for the experiment class and 0.955 for the control class, indicating statistical significance. It can be concluded that they match the normally distributed criteria (Sig α > 0.05). This suggests that the data displayed a pattern that is in line with a normal distribution.

In addition, the homogeneity of variance was assessed using homogeneity tests, yielding scores of 0.559 for the pre-test and 0.748 for the post-test. Both of these scores exceeded the significance criterion (Sig. α > 0.05), suggesting that the sample variances were equal. Therefore, the use of a parametric test was acceptable due to the combination of regularly distributed and homogenous data.

As a result of the statistical classification criteria, it was evaluated using a parametric test named independent sample t-test. The Independent sample t-test tabulated in Table 6 was used to see if the treatment significantly impacted the student's nature of science. Since the result Sig. (2-tailed) of the experimental class is 0.001, which is less than 0.05, it may be concluded that there is a difference in students' nature of science. While the result for Sig. (2-tailed) in the control class is 0.497, which is more than 0.05. There is no difference in students' nature of science. The conclusion result of the hypothesis test are tabulated in Table 6 below.

Table 6. The Hypothesis test using independent sample t-test of Control and Experiment Class

Hyphotesis Test		
Independent t-test	Experiment Class	Control Class
Sig. (2-tailed)	0.000 < 0.05	0.472 > 0.05

Sig α < 0.05		
Information	H_0 Rejected	H_0 Accepted
Conclusion	There is difference between pre-test and post-test result	There is no difference between pre-test and post-test result

The calculation of Normalized Gain (N-Gain) was deemed necessary to understand the improvement observed in both experimental and control groups. The comparison of N-Gain values derived from both classes is visually presented in Figure 3.

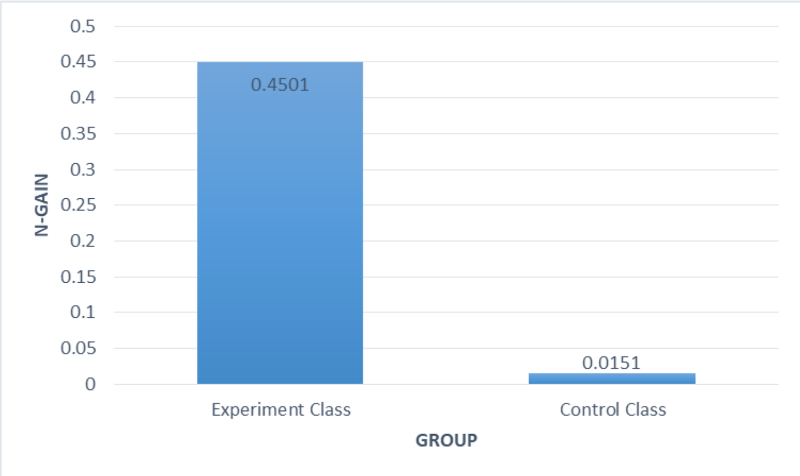

Figure 3. Graph of N-Gain of Control and Experiment Class

When compared to the Control Class, the graph for the Experiment Class shows a significantly higher value of 0.4501 for the measured metric. By comparison, the Control Class's bar shows a significantly lower value of 0.0151 for the same parameter. This visual representation effectively highlights the substantial difference in the measured metric between the Experiment Class and the Control Class. To contextualize these findings, the interpretation of N-Gain was further classified using the guidelines standard developed by Meltzer (2002), which is provided in Table 7.

Table 7. N-Gain Categories

N-Gain Score	Category
$g > 0.7$	High
$0.3 \le g \le 0.7$	Moderate
$g < 0.3$	Low

(Meltzer, 2002)

According to the established criteria, the N-Gain of 0.4501 in the experiment class falls within the category of moderate improvement. Conversely, the N-Gain of 0.0151 in the control class is categorized as indicative of low improvement. These results offer insights into the differential effectiveness of the interventions employed in the experiment and control groups, highlighting the experiment class's comparatively more substantial enhancement in the targeted outcomes. The categorization of N-Gain in the experimental class and control class is shown in more detail in table 8.

Table 8. N-Gain of Control and Experiment Class Categories

Group	N-gain	Category of Gain
Experiment Class	0.4501	Moderate
Control Class	0.0151	Low

The Experiment Class, which attained an N-gain value of 0.4501, is represented by the first row. Based on the classification shown in the third column, this figure is categorized as a "Moderate" gain. On the other hand, the Control Class's results showed an N-gain value of 0.0151. This result falls into the "Low" gain category, signifying a markedly lower achievement level in comparison to the Experiment Class.

Students' Nature of Science on Each Issue

According to Chen, S. (2006), seven issues of Views on Science and Education (VOSE) measure students' understanding of Nature of Science. There are tentativeness, Nature of Observations, Scientific Methods, Theories and Laws, Use of Imagination, Validation of Scientific Knowledge, and Subjectivity and Objectivity. Those of seven NOS Issues were displayed into 15 questions using a five-point likert scale, each followed by a number of items representing diverse philosophical perspectives. To investigate the result, the data is also analyzed in each subsclae for pre-test and post-test. The summary of the N-Gain result for each subscale shown in table 9.

Table 9. The Summary of Students' Views on Science and Education (VOSE) on Each NOS Issues

GROUP	Component	NOS Issues of Views on Science and Education (VOSE)						
		Tentativeness	Nature of Observations	Scientific Methods	Theories and Laws	Use of Imagination	Validation of Scientific Knowledge	Subjectivity and Objectivity
1	Pre-test	69.12	65.05	64.38	64.42	61.68	61.57	64.07
	Post-test	77.89	76.42	79.64	76.53	77.47	78.02	78.58
	N-Gain	0.28	0.33	0.43	0.34	0.41	0.43	0.40
	Category	Low	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
2	Pre-test	70.17	65.68	62.98	64.49	62.52	58.68	62.56
	Post-test	68.07	65.05	64.91	66.73	64.63	60.39	63.32
	N-Gain	-0.07	-0.02	0.05	0.06	0.06	0.04	0.02
	Category	Low	Low	Low	Low	Low	Low	Low

Notes.
1 = Experiment Class
2 = Control Class

Based on table 9 above, the N-Gain scores in the experimental class vary between 0.28 and 0.43. All participants in the experimental group are classified as individuals with low academic performance. The N-Gain values demonstrate different levels of enhancement in scores, showing a favorable pattern in learning outcomes after the experimental intervention. In contrast, the control class exhibits N-Gain scores that span from -0.07 to 0.06. All participants in the control class, similar to the experiment class, are categorized as individuals with low achievement. The control class demonstrates a wider range of N-Gain values, which includes negative values, indicating a less consistent pattern of improvement.

According to the research results, the details of the students' nature of science can be described. The score of each aspect shows different result of students' acquisition between the pre-test and post-test. The seven issues were categorized as low to medium improvement. In the experiment class, there are six issues which categorized as medium improvement (nature of observations, scientific methods, theories and laws, use of imagination, validation of scientific knowledge, and subjectivity and objectivity), and only one issue that has been categorized as low improvement, that is tentativeness. Meanwhile, in the control class, all of the issues were categorized as low improvement, with two issues concluding a negative improvement (tentativeness and nature of observation). A comparison of N-Gain in each NOS Issue between experimental and control classes is depicted in Figure 4.

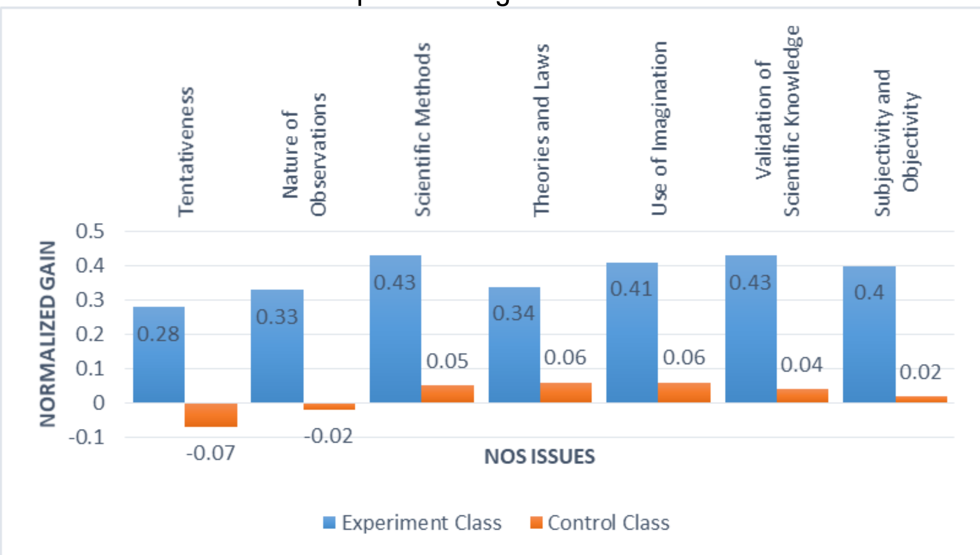

Figure 4. Comparison of N-Gain in each NOS Issues between experimental and control class.

Discussion

Students' Views on Science and Education (VOSE)

Based on the result, the N-Gain in the experiment class is 0.4501, indicating a favorable score increase. All individuals enrolled in this class are classified as low achievers. The N-Gain value, being solitary, indicates a moderate improvement, indicating a noticeable positive effect from the STEM engineering design process intervention. On the other hand, the control class demonstrates an N-Gain of 0.0151, which also classifies all individuals as poor achievers. Although positive, the N-Gain value in the control class is significantly lower than that of the experiment class. This indicates a lower level of score enhancement among the individuals in the control group. Directly comparing the N-Gain values between the experiment and control classes highlights the differences in the effectiveness of the interventions. The experiment class, with its higher N-Gain of 0.4501, indicates a significant improvement in scores, highlighting the potential effectiveness of the STEM–EDP approach in enhancing learning outcomes for underperforming students. The N-Gain values for the experiment and control classes indicate that the intervention in the experiment class had a significantly greater positive effect on students' understanding of the Nature of Science (NOS). The experiment class exhibited a higher N-Gain, indicating a more significant enhancement in scores for low-achieving pupils in comparison to the control class. However, it is crucial to thoroughly analyze the study's constraints and other factors that may distort the results to accurately interpret these findings.

The engineering design process is a component of the STEM discipline that introduces students to activities similar to those of engineers as part of the learning process. According to the results, there is an important gap in students' understanding of the nature of science between the control class and the experiment class (H_0 rejected and H_1 accepted). This result can be obtained by implementing the engineering design process in the experiment class. Beginning with defining a problem, the researcher initiates by presenting the students with real-life problems related to clean water. Students will immerse themselves in the role of a villager tasked with solving the problem of providing clean and safe drinking water to their community. The challenge is to create a tool that meets the above criteria and restrictions. Thus, it is essential to define the problem at the beginning of the engineering design process (Karsli Baydere & Bodur, 2022). The second phase is ingathering information. In this process, students will deal with a lot of information they get from different resources. However, students need to sort out the information gathered based on the problem given (Han & Shim, 2019). The next phase is implementing the best solution. This stage will determine whether their design will produce a tool that fits their hypothesis. The activity is shown in the figure 5.

Figure 5. Students making the water filtration prototype

While students turned their design into a real tool, they undergo procedural knowledge, scientific method, and also the use of imagination, which in line with nature of science component. It gives them a deeper understanding of nature of science through EDP process. This is one factor that makes difference between the experimental and control classes. In contrast, the control class used a traditional learning approach, where the water filtration equipment project only relied on instructions outlined in worksheets. Notably, this class is not involved in discussions or subsequent evaluation stages aimed at improving the product. Consequently, it can be concluded that students in the control group lacked comprehensive exposure to the scientific method, as their learning experiences lacked the depth and interactive elements observed in the experimental group's methodology.

The final phases involve evaluating the optimal option and reflecting on it. During this phase, students will observe whether their water filtration technology provides a positive outcome. The students finalize their water filtration tool design by considering the purified water's pH level. Students directly made a redesign of their water filtration tool when they found it didn't meet their expected result. The redesigned water filtration tools are shown in Figure 6.

Figure 6. The redesigned water filtration tools from two groups of experiment class

In addition, in this phase, students use scientific theory to think effectively about making water filtration tools (content knowledge). They determine if the right procedure has been followed and the conclusions are justified (procedural knowledge). Lastly, they can assess the procedures' appropriateness and determine if the data gathered meets the hypothesis (epistemic knowledge). In terms of the efficacy and completeness of the water filtration equipment, it can be seen that the experimental class product has superior water distillation capabilities compared to the control class product. This gap could be caused by the strong discussion and evaluation activities integrated into the Engineering Design Process (EDP) in the experimental group, which aimed to improve the quality of the final product. Additionally, it is noteworthy that the level of discourse in the experimental classroom surpassed the level of discussion in the control classroom, with more focused discussions occurring among students and between students and teachers, thereby encouraging effective communication. Recognizing the importance of oral language skills, which serve as the foundation of literacy (Dockrell et al., 2015), the high degree of deliberative interaction observed in the experimental classroom contributed to the development of these basic skills related to the issue in nature of science. Additionally, research shows that certain forms of verbal exchange, such as collaborative discussion and problem solving, play an important role in assisting children's understanding of academic subjects (Resnick et al., 2010). This is more or less a factor in why the experimental class have deeper understanding in the nature of science.

According to the previous result, if the students are given opportunities to engage with science and engineering in ways that scientists and engineers actually do, it will give them independence in evaluating what is known, allowing them to become scientifically literate (Allison & Goldston, 2018). In contrast, the core of scientific literacy is related to understanding NOS (Khishfe & Lederman, 2007). Another study concludes that STEM-EDP learning might enhance student learning results because of understanding science concepts and contents (Hammack et al., 2015; Ilmi et al., 2021). Based on all of those previous studies, this study also had a positive result in enhancing student's nature of science after implementing STEM-EDP.

Students' Nature of Science on Each Issue

Based on pre- and post-test results, the research findings show varied degrees of progress in students' comprehension of the nature of science across seven important domains. The experiment class demonstrated medium improvement in six areas: the nature of observations, scientific methods, theories and laws, the use of imagination, the validation of scientific knowledge, and subjectivity and objectivity. On the other hand, their understanding of the tentative nature of science showed very little improvement. All seven categories showed minimal improvement in the control group, and two of them—tentativeness and the type of observations—even showed negative growth. In comparison to the control condition, these findings imply that the experimental intervention significantly improved students' conceptual grasp of the nature of science.

The comparison of N-Gain scores between the experiment and control classes highlights a significant disparity. The experiment class, on average, demonstrated a positive enhancement, suggesting that the STEM learning intervention had a favorable impact on the academic performance of underperforming children. The experiment class's positive N-Gain values offer initial proof of the effectiveness of the STEM engineering design process. The application seems to benefit the academic performance of underachieving pupils, as evidenced by their elevated scores. This in line with the previous research that stated STEM also does not only focus on science content but also tends to critical thinking, reasoning, understanding, and the scientific investigation process, which in this case is in line with the concept of nature of science (Eroğlu & Bektaş, 2022). Conversely, the control class exhibited a varied pattern, with both positive and negative N-Gain values, indicating a lack of uniform progress across all pupils.

Based on the result, the tentativeness subscale gained low improvement in both classes and shows negative improvement in the control class. This issue focused on the changes of scientific knowledge, whether it is durable or can be changed. there are one main statement that is “Even if the scientific investigations are carried out correctly, the theory proposed can still be disproved in the future,” and followed by three Likert-scale statements such as “Scientific research will face revolutionary change, and the old theory will be replaced” or “With the accumulation of research data and information, the theory will evolve more accurately and completely, not being disproved.” The low normalized gain in the experiment and control class can be caused by learning that does not refer to the tentativeness of scientific knowledge, so some students still do not have a deep understanding of the issue. Other things that can be considered: The students believed that the tentativeness of scientific knowledge was mainly due to the discovery of new facts and evidence (Rai, 2017). Similar findings was reported by researchers in other countries (Mueller & Reiners, 2023) . Meanwhile, the control class, which experienced a decline in post-test results, shows that most students still do not understand the issues presented in the questionnaire.

On the other hand, the validation of scientific knowledge has the biggest N-Gain gap between the experiment and control class. The main statement, “When two different theories arise to explain the same phenomenon (e.g., fossils of dinosaurs), will scientists accept the two theories at the same time?” followed by several further statements in the form of a Likert-scale such as “No, because there is only one truth, scientists will not accept any theory before distinguishing which is best” reflect the empirical evidence, paradigm, parsimony, authority and also intuition in nature of science. This could be achieved when students learn meaningfully (Andrews et al., 2023). The experimental class that uses STEM engineering design process can make the learning more active and make students more interested in learning science. The phases of the engineering design procich require critical thinking and problem solving, where the phases start from hypothesis, designing, trying and deciding whether the solution is good enoumakingakes them understand more about the validation of scientific knowledge (how the science community accepts a theory).

For other issues such as nature of observations, scientific methods, theories and laws, use of imagination, and subjectivity and objectivity shows positive improvements in both classes. In the experiment class, all the five issues gain the moderate improvement with not too much different normalized-gain scores. In control class, the nature of observation experience a negative result of normalized-gain (-0.02) and a positive result for the rest of it and categorized as low improvement (g < 0.3). The wider spectrum of N-Gain values seen in the control group shows that STEM engineering design process-based learning applied in the experimental class is more successful than conventional learning applied in the control class to increase students' understanding of the nature of science.

Conclusion

This study aimed to enhance student's nature of science using stem engineering design processes in elements, compounds, and mixtures topic. From the research that has been done, the N-Gain of nature of science in experiment class obtained as much as 0.4501, which is categorized as a moderate level of improvement. However, in the control class, N-Gain is obtained as much as 0.0151, which is also categorized as low level of improvement. Based on the result, STEM design thinking significantly improves students' understanding of science. This can be seen from the N-Gain in the experiment class, which has a higher N-Gain than control class and is classified as a moderate improvement. The result of this study shown that STEM-EDP may be considered as learning model in order to sharpen students' nature of science. This study has the potential to significantly impact scientific education by motivating science teachers to include the core ideas of NOS and STEM-EDP into the curriculum for junior high school students.

Future research could examine the possibility of prolonging the duration of the STEM Design Thinking session. Extending the duration of the study may enable a more thorough investigation of the intervention's influence, potentially revealing hidden effects that may not become apparent within a shorter time period. Expanding the time scope seeks to offer a more thorough comprehension of the potential influence of STEM Design Thinking on students' understanding of the nature of science. By extending the duration of the study, researchers can explore the intricacies of the intervention and its long-lasting impacts, providing significant knowledge to the field of STEM education.

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