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ENHANCING PRE-SERVICE TEACHERS' SCIENCE PROCESS SKILLS THROUGH OPEN-ENDED AND GUIDED INQUIRY-BASED LEARNING

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Abstract

This study investigates the effectiveness of open-ended and guided inquiry-based learning modules in enhancing Science Process Skills (SPSs) among pre-service science teachers in Indonesia. The study responds to the limited research on student teachers' mastery pf SPSs during the implementation of the Independent Curriculum in Indonesia. A quasi-experimental non-equivalent pretest-posttest control group design was employed involving 204 pre-service teachers enrolled in Environmental Education courses, distributed across open-ended inquiry, guided inquiry, and conventional learning groups. Data were analyzed using two-way ANOVA and factorial MANOVA (3×2), considering gender and study program (Biology and Physics) as moderating variables. The results reveal statistically significant improvements in SPS for both inquiry-based groups compared to the conventional group ($p < 0.001$). Gender-based differences were also observed: female participants outperformed males in the guided inquiry group, while males performed better in the open-ended group. In addition, no significant differences were found between study programs. The findings underscore the potential of inquiry-based learning modules to foster key scientific competencies and suggest that gender-responsive strategies may further optimize student understanding of SPSs. This study contributes to international discussions on competency-based science teacher education and offers practical insights for curriculum design in national and global contexts.

Keywords: *Science Process Skills; Pre-service Science Teachers; Open-ended Inquiry; Guided Inquiry.*

A. Introduction

Science process skills (SPSs) are crucial for developing science concept knowledge and scientific attitudes at all levels of education. Nevertheless, a large number of studies have evidenced that students have low understnding of SPSs and receive little training on them (Al-Rabaani, 2014; Athiyyah et al., 2020; Nicol et al., 2023) and less encouragement for the tools and practical resources (Nuangchalerm & Prachagool, 2010).

Many scholars suggest that it is relevant to use scientific inquiry to train students with SPSs. Scientific Inquiry is a learning model where students need to understand science concepts through experimentation (Bain et al., 2023; Hall & Hampden-Thompson, 2022; Mikropoulos & Iatraki, 2023; Sudirman et al., 2023; Valdez-Ward et al., 2023; Weder et al., 2023). Scientific inquiry can stimulate thinking skills and increase interest and motivation to learn science because it is a 'hands-on' and 'minds-on' activity (Margunayasa et al., 2019; NRC, 2000; Perla et al., 2023) and also can increase a positive and scientific attitude (Hafizan et al., 2012; Thuneberg et al., 2017).

There are four reasons why SPSs is relevant for training science students. *First*, scientific development is accelerating, making it impossible for educators to convey all the facts and concepts to their students. Therefore, SPSs is a skill that requires student knowledge acquisition (Karsli & Ayas, 2014) and also understanding of the knowledge acquired (Bati et al., 2010). *Second,* students better understand complex and abstract concepts when concrete examples are presented. *Third*, scientific discoveries are relative, not absolute. All concepts found are still open to questioning and investigation. *Fourth*, in learning, the development of concepts should not be separated from process competencies and values (Rustaman, 2008). Therefore, educators' good understanding of SPS will enable them to use the skills in the classroom.

Since teachers' SPSs are crucial, training prospective teachers on these skills is vital. Students must also be taught to conduct scientific research and develop a better understanding of the concepts under study

(Jannah, 2020), solve problems (Hafizan et al., 2012), and create higher mental processes such as critical and creative thinking skills and decision-making skills (Adnyana & Citrawathi, 2017). Teachers with good knowledge of science concepts can usually master SPS well, too (Radford et al., 1992).

However, previous SPSs studies on pre-service teachers in Indonesia, the United States, Malaysia, and Turkey show unsatisfactory results and fall in the lower category (Adlim et al., 2020; Chabalengula et al., 2012; Eryilmaz & Kara, 2016; Susilawati et al., 2019). Several factors influence SPSs for pre-service teachers in several countries. These factors include differences in study programs (Rustaman, 2008) and gender (Al-Rabaani, 2014; Lincoln et al., 2004; Özgelen, 2012; Rumalolas et al., 2021; Rustaman, 2008). Therefore, professional educators must develop SPS.

Teachers should possess a strong understanding and must exhibit competence in SPSs to effectively teach the skills (Nicol et al., 2023). Professional educators should also have conceptual knowledge (Vergara et al., 2021), scientific skills and attitudes (Jannah, 2020; NRC, 2000), and good pedagogical skills (Astalini et al., 2023; García-Vandewalle García et al., 2023) because they must plan and implement different learning strategies for science learning, different learning methodologies, and models.

To produce good, memorable learning and improve SPS for pre-service teachers, an inquiry is suitable (Astalini et al., 2023) as they need to use it when teaching. The effectiveness of inquiry-based science learning, predominantly guided inquiry for pre-service teachers, can increase self-confidence, develop various skills, and develop an understanding of content knowledge and scientific knowledge among pre-service teachers (Lamminpää et al., 2023; Stamer et al., 2021).

Although guided inquiry can lead to good science learning, the implementation of learning using inquiry is still a problem for educators in Indonesia (Rustaman, 2008). Previous studies show that SPS develops when students do activities given by the teacher, such as an experiment (Evriani

et al., 2017), and the quality of teacher learning does not change much after they have attended various workshops and training. Only those who have frequently attended workshops and conferences related to their areas of expertise improve their knowledge of the concepts they teach (Al Mamun & Lawrie, 2023; Sudirman et al., 2023; Uludağ & Semra Erkan, 2023). It was also found that many teachers were not creative and lack of knowledge in developing independent learning (Pamenang et al., 2020; Peretz et al., 2023), as most teach conventionally as they were taught at university (Mohajer et al., 2023; Peretz et al., 2023).

This study intends to assist lecturers in teaching Environmental Education courses and solve environmental problems through inquiry-based learning by developing an Inquiry-Based Science Learning Module (IBSLM). IBSLM is a learning module consisting of information that can facilitate lecturers in developing SPS in the learning of environmental knowledge of student teachers. IBSLM consists of five sections: 1) learning plan, 2) learning objectives, 3) hands-on activities, 4) learning materials, and 5) assessment. The IBSLM developed in this module consists of open-ended and guided inquiry modules. The former is that student teachers carry out experiments freely, which are fully controlled by pre-service teachers, whereas in the latter, the activities are guided by the lecturers.

B. Method

1. Research design and sample

The study employed a quasi-experimental non-equivalent pretest-post-test control group design (Creswell 2012). The quasi-experimental design aimed to identify the differences between the results of the control and treatment groups. It used a 3x2x2 factorial. The first independent variable is the learning model using the guided inquiry module, the open-ended inquiry module, and conventional learning. The second independent variable is study programs (Biology and Physics), and the third is gender (male and female). The design of this study is shown in Table 1 below.

Table 1. Research design

Class	Pretest	Treatment	Post-test
Experiment I (Open-ended inquiry)	O_1	X_1	O_2
Experiment II (Guided Inquiry)	O_1	X_2	O_2
Control (Conventional)	O_1	X_3	O_2

Table 1 shows that the three groups received a pretest at the initial meeting. Fourteen SPS questions were given as objective questions, where pre-service teachers chose the correct answers based on their initial knowledge of environmental learning about the basic concepts of environmental knowledge and their problems. Next, the treatment was conducted in two experimental and one control class based on the study programs (Biology and Physics). In experimental class I, environmental learning was performed using the open inquiry module, whereas in experimental class II, environmental learning was conducted using the guided inquiry module. Both are science learning modules that integrate the five steps of inquiry-based science learning (NRC, 2000).

The sample used in this study, as seen in Table 2, was 204 pre-service teachers studying at the Faculty of Education and Teacher Training, Universitas Islam Negeri Ar-Raniry Banda Aceh. The sampling method was random group assignment (Lavrakas et al., 2019).

Table 2. Number of pre-service teachers according to study program

Program studies	The number of pre-service teachers in the class			Total
	Experiment I (Open-ended inquiry)	Experiment II (Guided Inquiry)	Control (Conventional)	
Biology	35	33	36	104
Physics	33	34	33	100
Total	**68**	**67**	**69**	**204**

Table 2 shows that 204 pre-service teachers from two study programs, namely Biology and Physics, participated in this study. Of the 204 respondents involved in this study, 104 pre-service teachers (50.98%) were from the Biology study program and 100 (49.02%) from the Physics study

program. They were again divided into three different learning model classes: 68 (33.33%) were in the open-ended inquiry class (Experimental class I), 67 (32.84%) were in the guided inquiry class (Experimental class II), and 69 (33.82%) were in the conventional class (control class).

By gender, the respondents were 139 females (68.14%) and 65 males (31.86%). The biology study program's open-ended inquiry class involved 35 pre-service teachers, 10 males and 25 females. There were 33, 13 males and 20 females, for the Physics study program. The class that received a guided inquiry in the biology study program consisted of 33 pre-service teachers, 11 males and 22 females. The Physics study program involved 34, 11 males and 23 females. The conventional class of the biology study program involved 36, 10 males and 26 females. The Physics study program involved 33 pre-service teachers, 10 males and 23 females.

The instrument used fourteen multiple-choice questions that refer to the six constructs of SPS: observe, hypothesize, design experiment, experiment, apply the concept, and communicate. The questions in these six constructs are in the form of questions that enhance SPS related to environmental concepts that occur in daily life. The questions of each construct are developed based on the independent curriculum.

Furthermore, validity and reliability are essential in the data collection procedure. These two things are analyzed using Kuder Richardson 20 (KR 20). The validity of these six constructs is 0.80, while the reliability results are depicted in Table 3.

Table 3. Preliminary Study of SPS construction

No.	SPS Construction	1	2	3	4	5	6
1.	Observe	0.79					
2.	Hypothesis	0.	0.61				
3.	Design Experiments	0.	0.	0.73			
4.	Carry Out Experiments	0.	0.	0.	0.65		
5.	Application of the Concept	0.	0.	0.	0.	0.70	
6.	Communicate	0.	0.	0.	0.	0.	0.60
Mean				6.06			
Standard Deviation				2.44			
Skewness				0.170			
KR 20				0.079			

The results of the KR-20 analysis show the ability to observe (0.79), hypothesize (0.61), design experiments (0.73), carry out experiments (0.65), apply concepts (0.70), and ability to communicate (0.60). This shows that in the initial study, the teachers were relatively low in the ability to design experiments, carry out experiments, and communicate. Even though this ability is crucial, it must be mastered by the teacher. Meanwhile, the mean value indicates that the overall interpretation of scientific process ability is well-oriented, with a mean value of around 6.06. In contrast, the Kuder Richardson 20 (KR 20) value shows 0.079 > 0.05. This means that the instruments used in research are relatively constant or reliable.

All data obtained from pretest and post-test research instruments were analyzed using SPSS 22. The statistics used in this study's analysis are descriptive and inferential. Descriptive analysis is used to thoroughly describe the research subject, such as class, gender, and study program of the respondents. The statistics used are frequency, percentage, mean, and standard deviation. Inferential analysis was used to analyze the relationship between three independent and three dependent variables. The first independent variable is the class (open-ended inquiry module, guided inquiry module, and conventional learning).

The second independent variable is gender (male and female). The third variable is the study program (Biology and Physics). To determine the effectiveness of using the inquiry module in improving SPS, two-way ANOVA and a 3x2 Factorial MANOVA were involved. The two-way ANOVA test determines differences in SPS based on class, gender, and study program. The MANOVA test was used to analyze the hypothesis of the independent variable that produces the same mean vector for the dependent variable, and the Box's M test was used ($p>0.05$). Meanwhile, the MANOVA Factorial 3x2 test was used to analyze the impact of class and study programs on the six constructs of SPS.

Therefore, based on the analytical framework utilizing two-way ANOVA and 3x2 factorial MANOVA to examine the influence of class,

gender, and study program on students' science process skills (SPS), this study formulates the following hypotheses to be empirically tested.

H01 : The use of open-ended and guided inquiry modules in learning has a significant effect on pre-service teachers' SPS based on the study program.

Ha1 : The use of open-ended and guided inquiry modules in learning has no significant effect on pre-service teachers' SPS based on the study program.

H02 : The use of open-ended and guided inquiry modules in learning has a significant effect on pre-service teachers' SPS based on gender.

Ha2 : The use of open-ended and guided inquiry modules in learning has no significant effect on pre-service teachers' SPS based on gender.

H03 : The use of open-ended and guided inquiry modules in learning has a significant effect on the six constructs of SPS pre-service teachers based on gender and study program.

Ha3 : The use of open-ended and guided inquiry modules in learning has no significant effect on the six constructs of SPS pre-service teachers based on gender and study program.

C. Results and Discussion

This section presents the main findings of the study, which examined the effectiveness of open-ended and guided inquiry-based learning modules in enhancing pre-service teachers' science process skills (SPS). The results are analyzed based on instructional group, study program, and gender. The discussion further explores the implications of these findings for competency-based science education and teacher training practices.

1. Results

This study investigates *the effects of open-ended and guided inquiry modules on the SPS of the* pre-service teachers *undertaking Environmental Education courses based on class, gender, and study program and the* pre-service teachers' *SPS learning conventionally.*

The differences in SPS mastery of the pre-service teachers based on the study programs can be seen in Tables 4, 5, and 6.

Table 4. Mean and standard deviation of pretest and post-test SPS

Kelas	Study Program	N	Pretest		Post-test	
			Mean	Standard Deviation	Mean	Standard Deviation
Open-ended inquiry	Biology	35	44.49	22.123	69.59	14.426
	Physics	33	40.69	19.842	69.91	14.807
	Total	**68**	**42.64**	**20.978**	**69.74**	**14.503**
Guided Inquiry	Biology	33	41.55	17.076	73.16	12.630
	Physics	34	39.49	16.795	72.68	14.549
	Total	**67**	**40.51**	**16.837**	**72.92**	**13.536**
Conventional	Biology	36	45.83	13.376	42.26	15.960
	Physics	33	47.61	13.559	40.25	14.813
	Total	**69**	**46.68**	**13.394**	**41.30**	**15.342**

The analysis of open-ended inquiry scores shows that the pretest average for Biology and Physics study programs is around 42.64%, while the post-test score is around 69.74%. This shows a significant increase when using a guided inquiry module learning model. In guided inquiry, the average score on the pretest is around 40.51%, while the post-test is around 72.92%. In conventional inquiry, the average pretest shows 46.68%, and the post-test ranges from 41.30%. This can be seen in Table 5 below.

Table 5. Two-way ANOVA analysis of differences in SPS master

	Type III Sum of Squares	Df	Mean Power Two	F	Sig.
Class	41561.333	2	20780.666	97.686	0.000
Study Program	26.174	1	26.174	0.123	0.726
Class*Study Program	47.798	2	23.899	0.112	0.894
Standard Error	42120.376	198	212.729		
Total	846985.063	204			

The ANOVA test results show that the SPS of Physics and Biology pre-service teachers have significant differences. This can be seen from the significance value between study programs and classes with sig. values ranging from 0.894> 0.05. can be seen in Table 6.

Table 6. Scheffe's post-hoc examination of the differences in SPS mastery of pre-service teachers by class

Class (I)	Class (J)	Difference Means (I-J)	Standard Error	Sig.
Open-ended inquiry	Guided inquiry	-3.1728	2.510	0.451
	Conventional	28.4449*	2.492	0.000
Guided Inquiry	Open-ended inquiry	3.1728	2.510	0.451
	Conventional	31.6177*	2.501	0.000
Conventional	Open-ended inquiry	-28.4449*	2.492	0.000
	Guided Inquiry	-31.6177*	2.501	0.000

The two-way ANOVA analysis and Scheffe's Post Hoc test, as shown in Tables 4, 5, and 6, indicate no significant difference in mastery of SPS between the pre-service teachers who used open inquiry and those who used guided inquiry. Hence, pre-service teachers who use open-ended inquiry have the same mastery of SPS as those in the guided inquiry class.

Several aspects can influence the Mastery of SPS, such as the learning model provided, gender, and other factors. Table 7 shows the differences in average scores between male and female pre-service teachers in mastering SPS.

Table 7. The results of the pretest and post-test of SPS mastery of pre-service teachers between classes by gender

Class	Gender	N	Pretest		Posttest	
			Mean	Standard Deviation	Mean	Standard Deviation
Open-ended inquiry	Male	23	35.09	17.879	72.05	15.215
	Female	45	46.50	21.569	68.57	14.154
	Total	**68**	42.64	20.978	69.74	14.503
Guided Inquiry	Male	22	41.55	14.727	70.77	13.208
	Female	45	40.00	17.914	73.96	13.718
	Total	**67**	40.51	16.837	72.92	13.536
Conventional	Male	20	46.42	11.703	49.64	13.409
	Female	49	46.79	14.139	37.90	14.883
	Total	**69**	46.68	13.394	41.30	15.342

The analysis shows that male pre-service teachers had higher SPS than females in open-ended inquiry. Meanwhile, for the guided inquiry, the SPSs of female pre-service teachers were higher than those of males. The difference is statistically significant, as shown in Table 8.

Table 8. Two-way ANOVA analysis of differences in SPS mastery based on gender

	Type III Sum of Squares	Df	Mean Power Two	F	Sig.
Class	576.287	2	288.143	72.946	0.001*
Gender	13.922	1	13.922	3.524	0.06
Class*Gender	31.727	2	15.863	4.016	0.02*
Standard Error	782.114	198	3.950		
Total	16601.000	204			

The significant value of the difference in pre-service teachers' SPSs between groups based on class gender was with a value of F = 4.016 and a considerable value (p) = 0.02 (p<0.05). This suggests that, based on gender, there is a significant difference in pre-service teachers' SPSs between the open-ended and guided inquiries. There is also an interaction between class and gender on SPSs. The interactions that occur are shown in Figure 1.

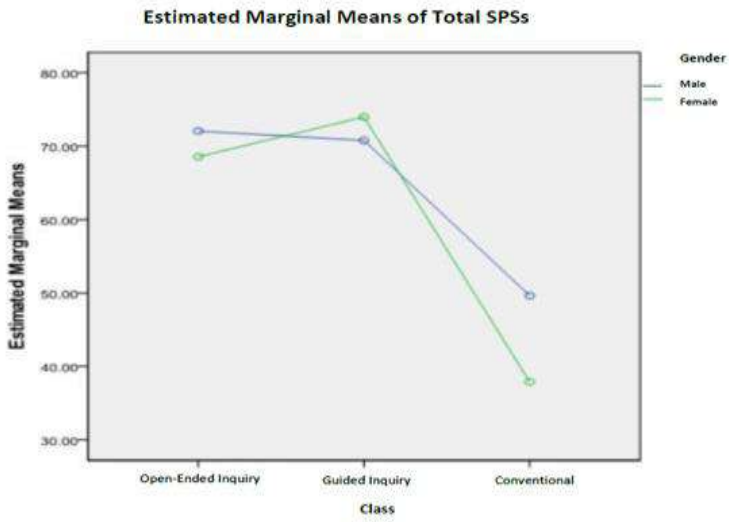

Figure 1. Interaction between groups and gender of pre-service teachers on SPSs

Table 8 and Figure 1 show a significant interaction between groups and gender in SPSs. The interaction between the group and the gender of pre-service teachers on SPSs, where female pre-service teachers in the guided inquiry had higher SPS than males. Meanwhile, male pre-service teachers have higher SPS than females in the open-ended inquiry and conventional classes. This suggests a significant interaction between groups and gender in pre-service teachers' SPSs.

Pillai's Trace is used for one class of dependent variables (pretest or post-test only of SPSs). Pillai's Trace test results in the Multivariate Test Table show that overall, there is a significant relationship between open-ended inquiry, guided inquiry, and conventional class [F (12,388) = 13.23, sig 0.000 p < 0.05] to the SPSs construct of observing skills, hypothesis skills, experimental design skills, experiment carrying out skills, concept application skills and communication skills. However, there is no relationship between the independent variables of Biology study program and Physics study program [F(6,193) = 0.078, sig 0.998 p> 0.05] and the effect of study program class interaction [F(12,388) = 0.061, sig 1.000 p> 0.05] on the dependent variable, namely SPS construct in observing skills, hypothesizing skills, experiment designing skills, conducting experiments skills, concept application skills and communication skills.

Table 9. Analysis of homogeneity of variance using Lavene's test

SPS Construction	F	df1	df2	Sig.
Observe	7.968	5	198	0.000
Hypothesis	1.794	5	198	0.116
Design Experiments	1.857	5	198	0.103
Carry Out Experiments	2.216	5	198	0.054
Application of The Concept	2.082	5	198	0.069
Communicate	0.570	5	198	0.723

As depicted in Table 8, the analysis reveals that the Levene's test for equality of variances indicates a statistically significant result for the skill construct of observing, with a significance value (sig.) of 0.000, which is less than the threshold of 0.05 (p < 0.05). This suggests that the

assumption of homogeneity of variance for the observing skill construct is violated. In contrast, the significance values for the other skill constructs—namely, formulating hypotheses, designing experiments, carrying out experiments, applying concepts, and communicating—are 0.116, 0.103, 0.054, 0.069, and 0.723, respectively, all of which exceed the threshold of 0.05 ($p > 0.05$). These results imply that for these particular constructs, the assumption of equal variances is met, thereby supporting the robustness of subsequent parametric analyses conducted on these variables.

Table 10. Mean and standard deviation of the SPS construct of pre-service teachers based on study programs and classes

SPS Construction	Study Program	Class	N	Mean	Standard Deviation
Observe	Biology	Open-ended inquiry	35	85.71	25.928
		Guided Inquiry	33	90.90	23.233
		Conventional	36	61.11	38.005
		Total	**104**	**78.84**	**32.450**
	Physics	Open-ended inquiry	33	89.39	24.230
		Guided Inquiry	34	92.64	21.785
		Conventional	33	59.09	38.435
		Total	**100**	**80.50**	**32.485**
Hypothesis	Biology	Open-ended inquiry	35	77.14	30.541
		Guided Inquiry	33	78.78	28.035
		Conventional	36	44.44	28.729
		Total	**104**	**66.34**	**33.006**
	Physics	Open-ended inquiry	33	77.27	30.849
		Guided Inquiry	34	79.41	27.846
		Conventional	33	42.42	28.287
		Total	**100**	**66.50**	**33.374**
Design Experiments	Biology	Open-ended inquiry	35	65.71	33.806
		Guided Inquiry	33	83.33	27.003
		Conventional	36	34.72	35.495
		Total	**104**	**60.57**	**37.953**
	Physics	Open-ended inquiry	33	65.15	31.831
		Guided Inquiry	34	83.82	26.743

SPS Construction	Study Program	Class	N	Mean	Standard Deviation
		Conventional	33	33.33	34.610
		Total	**100**	**61.00**	**37.321**
Carry Out Experiments	Biology	Open-ended inquiry	35	71.42	30.403
		Guided Inquiry	33	69.69	24.809
		Conventional	36	44.44	28.729
		Total	**104**	**61.53**	**30.553**
	Physics	Open-ended inquiry	33	72.72	30.849
		Guided Inquiry	34	69.11	24.663
		Conventional	33	42.42	28.287
		Total	**100**	**61.50**	**30.858**
Application of The Concept	Biology	Open-ended inquiry	35	46.66	27.057
		Guided Inquiry	33	50.50	31.316
		Conventional	36	24.99	23.059
		Total	**104**	**40.38**	**29.257**
	Physics	Open-ended inquiry	33	45.45	27.410
		Guided Inquiry	34	47.05	32.945
		Conventional	33	23.23	22.798
		Total	**100**	**38.66**	**29.860**
Communicate	Biology	Open-ended inquiry	35	78.09	22.784
		Guided Inquiry	33	75.75	22.473
		Conventional	36	49.07	24.543
		Total	**104**	**67.30**	**26.675**
	Physics	Open-ended inquiry	33	77.77	21.516
		Guided Inquiry	34	75.49	20.611
		Conventional	33	46.46	23.482
		Total	**100**	**66.66**	**25.950**

The results of the analysis of the mean and standard deviation of the SPS construct show that the average value in the ability to observe between Biology and Physics pre-service teachers is higher for Physics pre-service teachers (80.50). In terms of hypothesizing ability, Physics pre-service teachers obtained higher scores (60.50), Physics pre-service teachers had higher ability to design experiments (61.00), Biology pre-service teachers had higher concept application ability (40.38), and Biology pre-service

teachers had higher communication skills (67.30). These findings indicate that while Physics pre-service teachers tend to excel in procedural and investigative aspects of SPS, Biology pre-service teachers demonstrate stronger performance in conceptual understanding and the ability to convey scientific information. This distinction may reflect differences in curricular focus or pedagogical emphasis within the respective study programs.

Table 11. MANOVA analysis of differences in SPS constructs for pre-service teachers based on study program and class

Category	Leaning variable	Type III Sum of Squares	Df	Mean Squared	F	Sig.
Study Program	Observe	65.333	1	65.333	.075	.784
	Hypothesis	9.078	1	9.078	.011	.918
	Design Experiments	12.090	1	12.090	.012	.913
	Carry Out Experiments	9.578	1	9.578	.012	.912
	Application of The Concept	233.759	1	233.759	.306	.581
	Communicate	57.738	1	57.738	.113	.737
Class	Observe	40416.826	2	20208.413	23.208	.000
	Hypothesis	55063.044	2	27531.522	32.563	.000
	Design Experiments	85576.284	2	42788.142	42.223	.000
	Carry Out Experiments	34267.114	2	17133.557	21.726	.000
	Application of The Concept	24994.602	2	12497.301	16.346	.000
	Communicate	38580.510	2	19290.255	37.676	.000
Study Program* Class	Observe	287.457	2	143.729	.165	.848
	Hypothesis	67.461	2	33.731	.040	.961
	Design Experiments	30.089	2	15.045	.015	.985
	Carry Out Experiments	94.665	2	47.333	.060	.942
	Application of The Concept	45.577	2	22.789	.030	.971
	Communicate	61.235	2	30.617	.060	.942

The results in Table 11 indicate that there are no statistically significant differences in any of the six SPS constructs based on the study program, as all p-values are greater than 0.05. In contrast, the class factor shows a highly significant effect across all SPS constructs ($p < 0.001$), suggesting that students' class levels play a crucial role in shaping their science process skills. Furthermore, the interaction between study program and class is not statistically significant, indicating that the combined effect of these two factors does not influence SPS outcomes in a meaningful way.

2. Discussion

The two-way ANOVA test analysis indicates a significant difference in SPS mastery of pre-service teachers between open-ended inquiry, guided inquiry, and conventional group based on gender. This means female pre-service teachers in the guided inquiry had higher SPS than males. Meanwhile, male pre-service teachers in the open-ended inquiry groups have higher SPSs than females. This means using guided inquiry-based science learning modules impacts females, whereas open-ended inquiry impacts male pre-service teachers on SPS mastery. The results are contrary to those of some previous studies (Al-Rabaani, 2014; Astalini et al., 2023; Nicol et al., 2023) but consistent with those of other previous studies (Evriani et al., 2017; Kurniawan & Fadloli, 2016) showing that the SPS of female pre-service teachers is higher than that of males.

An analysis of the two-way ANOVA test shows no significant difference in SPS mastery of pre-service teachers based on study programs. This means that the science lessons received by Biology and Physics pre-service teachers are effective. This learning is effective because each topic of pre-service teachers' learning requires them to think critically and actively to develop SPS. This is in line with the results of the studies by Krathwohl (2002) and Marzano et al. (2009). It was also found that students who have gone through an active learning process can demonstrate complex thinking skills such as effective communication, cooperation, collaboration, and the ability to process information effectively and adequately (Knezek et al., 2023; Krathwohl, 2002).

Mastering active thinking skill strategies is also needed to assist professional teachers in developing teaching and learning strategies (Sudirman et al., 2023). There is no difference in the SPS of pre-service teachers for both Biology and Physics study programs because the lecturers had attended seminars and workshops related to innovative learning that improved their SPS. This study's results differ from those of previous studies by Jannah (2020) and Rustaman (2008) in that the SPSs of prospective Biology and Physics pre-service teachers had significant differences.

The results of the inference analysis using the 3 x 2 factorial MANOVA test based on the study program and class on the constructs of observing skills, hypothesizing skills, skills of designing experiments, and skills of applying concepts showed that the *mean* of the scores pre-service teachers who used guided inquiry in Biology and Physics study programs is higher than that of the open-ended inquiry class and the conventional class pre-service teachers. As for the skill constructs of carrying out experiments and communication skills, their means of the scores of pre-service teachers' classes using open-ended inquiry in the Biology and Physics study program are higher than those of students of the guided inquiry class and the conventional class. The results show that pre-service teachers with open-ended inquiry have high observing skills, hypothesis skills, experimental design skills, and concept application skills in both Biology and Physics study programs compared to those using guided and open-ended inquiry. All the skills fall into high-level skills (Krathwohl, 2002), which include the activities of formulating problems, designing and carrying out a simple investigation, analyzing and interpreting data, and activities identifying and analyzing other explanations to be made, as well as activities communicating procedures and results of investigations, and creating (Marzano et al., 2009).

In this study, for each hands-on activity in the guided inquiry-based learning, the pre-service teachers in both study programs have observation, hypothesis, experimental design, and good concept application skills. For hands-on activities designed to train teachers to observe, they carried out observations using various media based on the concepts being learned, such as real objects, models, pictures, or graphs. In addition to observing skill

aspects, the pre-service teachers' hypothesizing skills, experiment-designing skills, and concept-applying skills were also investigated through activities designed with hands-on activity. In the guided inquiry class in the Biology and Physics Study Program, the skill of creating hypotheses that the pre-service teachers have is not a good result. This is shown when pre-service teachers were asked to create hypotheses before the experiment was carried out. The ability of pre-service teachers to generate hypotheses is to guess or estimate from a research problem, make a hypothesis to connect two variables or make assumptions or conjectures (Margunayasa et al., 2019).

The skills of pre-service teachers in planning investigations and applying the concepts in this study have improved. Pre-service teachers in the guided inquiry classes in Biology and Physics study programs have the skills to prepare learning tools and materials before learning begins based on the concepts to be learned. The skills needed in designing experiments, such as determining the tools and materials to be used, the objects to be investigated, the factors or variables considered, the criteria for success, the methods and work steps, and how to record and process data to conclude (Lestari & Diana, 2018). During designing and experimentation, the teacher should direct the experiment under study, and during the experiment, the teacher should act as a facilitator.

The skills of doing experiments and communicating in the open-ended inquiry class of the Biology and Physics Study Program are higher than those of the guided inquiry class and the conventional class. The results of this study indicate that the activities of doing and communicating procedures and results of investigations at each meeting of pre-service teachers are good, as they were seen as very active in classroom discussions. The activeness of pre-service teachers in using this skill can be seen when each class finishes presenting the results of their group work, and other groups respond to the groups delivering the investigations through questions and answers.

However, some groups were not active in using this skill. This indicates that the inactivity of pre-service teachers in conducting question-and-answer sessions was due to the weak ability of middle school teachers

to communicate the results of investigations. Communication is a crucial skill that must be possessed, and guided inquiry can encourage students to communicate effectively, practically, and flexibly (Lusidawaty et al., 2020; Siantuba et al., 2023). A learning experience geared towards increasing scientific literacy (Wenning, 2011).

Inquiry learning should develop students' SPS. According to scholars (Jannah, 2020; NRC, 2000; Susilawati et al., 2019), the essence of inquiry-based science learning generally involves students in the activity of formulating problems, designing and carrying out a simple investigation, analyzing and interpreting data and activities identifying and analyzing other explanations that will be made as well as activities communicating procedures and results of investigations, and creating (Marzano et al., 2009). Meanwhile, according to Krathwohl (2002), it consists of recall, analysis, comparison, inference, and evaluation. The study results show that the initial hypothesis (H0) is accepted, where learning with the open-ended and guided inquiry modules significantly affects pre-service teachers' SPSs. Inquiry-based learning encourages the improvement of science process abilities (Astalini et al., 2023; Putra et al., 2016; Zuhri et al., 2023).

The importance of SPS in learning using inquiry (Al-Rabaani, 2014; Astalini et al., 2023; Zuhri et al., 2023). Teachers play an important role in developing students' SPS. Five aspects of the teacher's role in facilitating students with learning experiences that can develop process skills are: *first*, providing opportunities to use SPS in exploring equipment and materials, as well as phenomena directly (Oztay et al., 2022; Porter & Peters-Burton, 2021). This allows students to use their feelings and collect evidence to raise questions and form hypotheses based on existing ideas. *Second*, provide opportunities for discussion in class. All participants in the class are allowed to share ideas, and other participants listen to or refute the ideas given. *Third*, listen to students who provide ideas and evaluate products to get the process they use in forming ideas. For all stages of SPS, teachers can choose how students gather information and use evidence. *Fourth*, encourage a critical review of how experimental results are obtained.

During and after the experiment, students discussed how to get better data. *Fifth*, it provides examples of the necessary techniques for advanced skills, such as graphic drawing.

In this study, each activity in the hands-on activities and pre-service teachers' worksheets was designed to train them to have SPS. SPS develops hands-on and teacher worksheet activities such as observing skills, hypothesizing skills, experiment designing skills, conducting experiments skills, applying concept skills, and communication skills. Therefore, to improve SPSs, pre-service teachers' learning is done by inquiry or discovery. This is intended so pre-service teachers can develop high-level mental processes, such as critical thinking and decision-making (Nicol et al., 2023).

Learning through discovery is not just science learning but a way of using science to teach students to think (Hafizan et al., 2012; Noris et al., 2022; Rampisela et al., 2022). Through SPSs such as observing, hypothesizing, designing experiments, carrying out experiments, applying concepts, and communication, this study provides opportunities for pre-service teachers to discover new concepts and develop their knowledge to make learning meaningful. Supports Ausubel's theory (1986) that learning must be meaningful; in other words, inquiry-based science learning modules can relate the knowledge possessed by pre-service teachers to the knowledge they have just learned. Activities and exercises provided through hands-on and pre-service teachers' worksheets can relate the knowledge possessed by pre-service teachers to the knowledge learned.

SPS is the essence of science educators, and students must understand it. This relates to the limitations of science as a process, stating that science is not just facts. It is the ability to use fundamental knowledge to predict or explain various natural phenomena. Therefore, the need for SPS for pre-service teachers must be emphasized to enhance their teaching ability. Thus, learning that emphasizes the active process of science can change teacher behavior in teaching science.

The findings of this study also hold broader implications beyond the Indonesian context, particularly in addressing global challenges in science

teacher education. As demonstrated in both the open-ended and guided inquiry modules, inquiry-based science learning aligns with international educational goals that emphasize the development of critical thinking, scientific literacy, and inquiry competence among pre-service teachers (NRC, 2000; Nicol et al., 2023). These skills are considered essential by global institutions such as UNESCO and the OECD to meet the targets of Sustainable Development Goal 4, which advocates for inclusive and quality education for all. Moreover, the study responds to a recurring issue reported internationally—the persistent gap in SPS among pre-service teachers despite exposure to formal coursework (Chabalengula et al., 2012; Eryilmaz & Kara, 2016). By offering evidence of how structured inquiry modules can improve SPS, this research contributes valuable insights that can inform teacher education policies and instructional design in developing countries and diverse educational systems striving for competency-based learning outcomes.

D. Conclusion

The study was carried out to determine the pre-service teachers' mastery of SPS *by class, gender, and study program, who were taught using open-ended and* inquiry modules and taught *conventionally*. After analyzing and discussing the findings, it can be concluded that SPS, including observation, hypothesis, design experiment, and the application of the concepts, among pre-service teachers enrolled in two programs, Physics and Biology, as well as to analyze differences by gender. The findings indicate a significant difference in SPS mastery based on gender, but not between the study programs.

Student teachers studying Biology and Physics who used an inquiry module demonstrated an improvement in SPS mastery. The results suggest that open-ended and guided inquiry modules effectively enhance Pre-service teachers' mastery of SPS. Overall, inquiry-based learning is more effective than conventional teaching methods for improving mastery of SPS among Pre-service teachers.

Additionally, the study indicates that the inquiry-based modules have a similar positive impact on both male and female student teachers, increasing their SPS mastery. However, it is essential to note that the study included a higher proportion of female student teachers, averaging 68.14%, compared to 21.86% of male student teachers in guided inquiry and conventional classes. Thus, the results may not represent each group's experiences comparably.

Moreover, the focus of this study does not delve into how teacher educators, differentiated by gender, teach Pre-service teachers to master SPS. Therefore, further research is warranted to explore this aspect more thoroughly.

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