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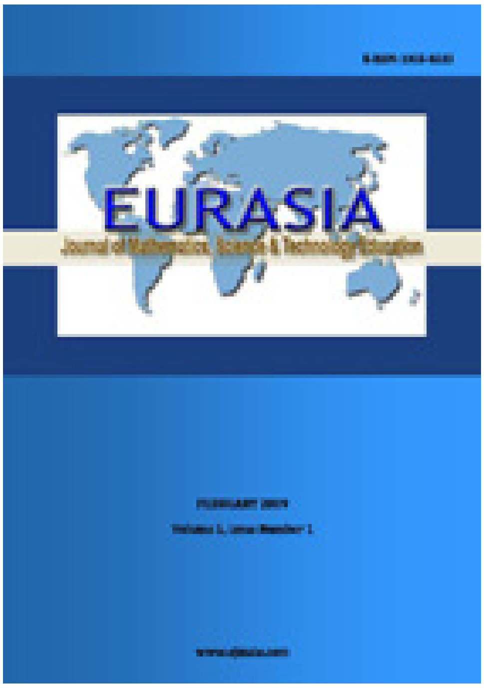

How Pre-service Teachers' Understand and Perform Science Process Skills

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This study explored pre-service teachers' conceptual understanding and performance on science process skills. A sample comprised 91 elementary pre-service teachers at a university in the Midwest of the USA. Participants were enrolled in two science education courses; introductory science teaching methods course and advanced science methods course. Data were collected through a questionnaire. Results showed that pre-service teachers had limited conceptual understanding of science process skills. On the other hand, they had higher performance on the science process skills. Whilst majority of the participants were unable to provide correct definitions of the science process skills, they performed well on the test that involved novel situations of the process skills. The findings have implications for science teaching, learning and teacher education.

Keywords: conceptual understanding, performance, pre-service teacher, science process skills

INTRODUCTION

Science process skills are transferable intellectual skills, appropriate to all scientific endeavors (NSTA, 2000). Science process skills are in two categories which are basic and integrated skills. Basic process skills include observing, inferring, measuring, communicating, classifying, predicting, using time space relations and using numbers. Integrated process skills include controlling variables, defining operationally, formulating hypotheses, formulating models, interpreting data and experimenting,). Current USA science education reforms (American Associaton for the Advancement of Science [AAAS], 1993) and National Science Education Standards (National Research Council [NRC], 1996) emphasize the teaching of science process skills in K-12 science classrooms. Anderson (2002) also states that science process skills form an important part of scientific inquiry and consequently promote scientific literacy among students. Therefore, science teachers must be proficient in science process skills on a multitude of levels, and must have the knowledge and understanding to teach the science process skills. In view of this, several studies have been done on inquiry science teaching and learning among teachers (Boardman & Zembal-Saul 2000; Dana, Boardman, Friedrichsen, Taylor, & Zembal-Saul 2000; Zembal & Oliver 1998), conceptions of science teaching (Gao, 2002), and teachers' familiarity and interest in science process skills (Mbewe, Chabalengula, & Mumba, 2010). However, research studies in the domain of science process skills rarely discuss elementary education pre-service teachers' conceptual understanding of and performance on the science process skills. Yet, conceptual understanding correlates highly to performance in specific topic areas of science. As such conceptual understanding is widely acknowledged as one of the central goals of science education (Barbosa & Alexander, 2004).

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State of the literature

- Though science process skills form an integral part of inquiry teaching (Anderson, 2002; Minstrell & van Zee, 2000), and emphasized in science education reforms (AAAS, 1993; NRC, 1996), some studies have demonstrated that pre-service teachers have poor understanding of the process skills (e.g. Emereole, 2009; Mbewe, Chabalengula & Mumba, 2010).
- A few studies in the domain of science process skills rarely discuss elementary education pre-service teachers' conceptual understanding of and performance on the science process skills.

Contribution of this paper to the literature

- Our pre-service teachers' limited conceptual understanding of the science process skills is consistent with the findings in previous studies (e.g. Emereole, 2009; Farsakoglu, Sahin, Karsli, Akpinar & Ultay, 2008; Mbewe, Chabalengula & Mumba, 2010).
- However, a unique contribution to the literature is that whilst pre-service teachers were unable to provide correct definitions of the science process skills, they performed well on the test that involved novel situations of the process skills. A possible explanation for this good performance could be that the performance test items were presented in a real-world type situation, which could have assisted the pre-service teachers in solving them because they were familiar with the contexts.
- The poor conceptual understanding held by the pre-service teachers in our study is of great concern and a call to action on the part of science teacher education and professional development programs. As such, we recommend an explicit intervention on science process skills in teacher education programs for pre-service teachers to develop conceptual understanding of the science processes.

The premium placed on conceptual understanding is illustrated by its prominence as an objective in the National Assessment of Educational Progress (NAEP) science assessment (O'Sullivan, Reese, & Mazzeo, 1997). Among the definitions of characteristic elements of knowing and doing science, conceptual understanding is included. Similarly, Settlage and Southerland (2007) viewed the science process skills as an integral feature of the actions of the scientific culture, although not as all there is to science. Settlage et al further state that teaching with an eye toward science process skills is an appropriate entry point for beginning elementary and middle school teachers. As a result, they proposed that science process skills serve as a very important way for beginning teachers to learn about science teaching. Therefore, teachers should possess a strong conceptual understanding and be able to perform well on the science process skills if they have to effectively teach them in their classrooms. Scharmann (1989) points out that science process skills foster significant increases in subject matter understanding and science content knowledge, arguing that science content and science process skills should be taught together as they complement each other. Similarly, Rillero (1998) points out that both science content and science process skills are mutually valuable and complementary. Settlage and Southerland (2007) also emphasize how the science process skills provide a foundation for inquiry.

Though science process skills form an integral part of inquiry teaching (Anderson, 2002; Glynn & Duit, 1995; Minstrell & van Zee, 2000), and emphasized in science education reforms (AAAS, 1993; NRC, 1996), some studies have demonstrated that pre-service teachers have poor understanding of the process skills (e.g. Emereole, 2009; Mbewe, et al., 2010). For instance, Emereole (2009) investigated conceptual understanding of science process skills among high school pre-service science teachers in Botswana. Emereole's study found that pre-service high school science teachers did not have sufficient conceptual understanding of science process skills. Similarly, many studies have examined teachers' understanding of inquiry and have concluded that they lack a sufficient understanding of such a process (Lotter, Harwood, & Bonner, 2007). Mbewe, Chabalengula, and Mumba (2010) found that nearly all pre-service elementary teachers were unable to provide correct definitions and explanations of the basic and integrated science process skills, but the majority of them provided partially correct and incorrect answers. Yet, science process skills are essential for teaching science content knowledge and scientific inquiry (Cain, 2002).

Although previous research has examined teachers' conceptual understanding of the science process skills, few studies, if any, have examined the extent to which elementary education pre-service teachers are able to translate their conceptual understanding to novel and everyday life situations involving science process skills. Yet, it is important for the pre-service teachers to demonstrate a sound conceptual understanding and be able to perform well on test items involving novel situations of the science process skills in order to effectively create conditions for their development among their students. Therefore, this study attempted to examine pre-service teachers' conceptual understanding of and performance on science process skills.

Research Questions

To what extent do elementary education pre-service teachers conceptually understand the science process skills? To what extent are the elementary education pre-service teachers' understandings of science process skills influenced by demographics? What is the pre-service teachers' performance level on novel situations involving science process skills? To what extent is the elementary education pre-service teachers' performance on science process skills influenced by demographics? What is the relationship between pre-service teachers' conceptual understanding of and their performance on science process skills?

METHODOLOGY

This study was conducted in an elementary teacher education program at a university in the Midwest of the USA. A sample comprised 91 pre-service teachers who were enrolled in two science education courses: an introductory science teaching and advanced science teaching methods courses. The introductory science methods course is mainly focused on developing science process skills among pre-service teachers while the advanced science methods course is focused on science concepts in life, physical, earth sciences, and how to teach these concepts. None of the participants had a school teaching experience. Table 1 shows the profiles of the participants.

Instrument

Data was collected through two tests; *Science Process Conceptual Understanding Test* (SPCUT) and *Science Process Performance Test* (SPPT). The SPCUT had two sections. The first section was intended to collect demographic information of the participants such as gender, teaching subject and number of science courses taken at college. Section 2 had the conceptual understanding science process skills test items that were adapted from the test developed by Emereole (2009). This section required the participants to define or explain the following basic and integrated science process skills: *observe, classify measure, infer, predict, communicate, hypothesize, experiment, identify variables, formulate models, interpret data,* and *graphing.*

The SPPT had 48 multiple choice test items. The test was compiled using questions from published reliable and valid process skill performance tests which included: the Test of Integrated Process Skill II by Burns, Okey, and Wise (1985), the Test of Basic Process Skills by Padilla, Cronin, and Twiest (1985), the Virginia Standards of Learning Assessments by Virginia Department of Education (2007), and the science assessment framework of the National Assessment of Educational Progress (NAEP) by the National Assessment Governing Board [NAGB] (2005). The wording and format of the questions were not changed in any way from the original instruments. Each multiple choice item was matched with a specific science process skill, determined either by the original instrument author or, when not available, by the researchers. The compilation of questions was done to obtain a wide variety of questions and skills. Of the 48 questions, 19 questions focused on the six basic process skills; *observe, classify, communicate measure, infer,* and *predict.* The remaining 29 questions focused on the integrated process skills; *experiment, identify variables, formulate models, interpret data,* and *graphing.* The researchers attempted to obtain at least three questions to address each skill in order to gain multiple opportunities to examine performance on a particular skill without fatiguing the participants. By compiling all the questions and arranging them according to the science process skill they addressed, the researchers then picked out several questions that assessed the particular skill using a variety of formats. For example, questions on *classification* asked participants how they would classify a group of items, or fit an item into a provided classification system. Some questions provided scenarios and asked subsequent questions attending to multiple skills, thereby increasing the total number of items for some skills. For example, questions 5-8 all refer to a scenario about growing tomato plants and address the skills of *hypothesizing* and *identifying variables.*

Table1. Participants' Profiles

Demographics	Division	Science Methods Course Level		N=91
		Introductory (n=60)	Advanced (n=31)	
Teaching subject major	Science	18	9	27
	Non-science	42	22	64
Taken integrated science courses	Yes	38	22	60
	No	22	9	31
Number of College Science Courses taken	1-3 courses	34	3	37
	4-6 courses	26	28	54
Gender	Female	50	25	75
	Male	10	6	16

Table 2. Percentages for Conceptual Understanding of Process Skills by Course Level

SPS Name	SPS Type	Incorrect (%)		Partially Correct (%)		Correct (%)	
		IC	AC	IC	AC	IC	AC
Classifying	Basic	8.3	16.1	90.0	77.4	1.7	6.5
Observing	Basic	15.0	16.1	85.0	83.9	0.0	0.0
Measuring	Basic	23.3	29.0	76.7	67.7	0.0	3.2
Predicting	Basic	40.0	64.5	58.3	35.5	1.7	0.0
Communication	Basic	61.7	22.6	38.3	74.2	0.0	3.2
Inferring	Basic	75.0	67.7	25.0	32.3	0.0	0.0
Hypothesizing	Integrated	41.7	67.7	58.3	25.8	0.0	6.5
Interpreting data	Integrated	55.7	51.6	43.3	35.5	0.0	12.9
Experimenting	Integrated	61.7	35.5	36.7	61.3	1.7	3.2
Formulating models	Integrated	88.3	93.5	11.7	6.5	0.0	0.0
Identifying variables	Integrated	88.3	96.8	11.7	3.2	0.0	0.0
Graphing	Integrated	95.5	100.0	3.3	0.0	1.7	0.0

IC: Introductory course
AC: Advanced Course

Data analysis

Data analyses involved computing reliability values for conceptual understanding and performance tests. The SPCUT instrument had a very high Cronbach alpha reliability value of 0.935. To ensure validity of the compiled SPPT, three science education experts were asked to identify each question with its associated process skill being tested. A Cohen's kappa score of 0.764 was found, and indicates a strong inter-rater reliability for the performance test.

Participants' responses to the SPCUT were scored and categorized as correct, partially correct, and incorrect. The responses were compared to the standard answers used by Emereole (2009). The correct response was assigned a value of 3, partially correct response was assigned a value of 2, and an incorrect response was assigned a value of 1. A response was considered correct if it contained all the aspects in the standard answers completely. The response was considered partially correct if it contained some of the aspects in the standard answer. The response was considered incorrect if it was either completely wrong when compared to the standard answer or if the question was not answered or left blank. Then, the responses were analyzed and coded to identify recurring themes. Participants' responses to the SPPT were either scored as correct or incorrect as there was only one correct answer for each test item. Then, statistical tests were done, which included t-tests, ANOVA and person correlation coefficient.

RESULTS

Conceptual understanding of science process skills

Table 2 below shows that very few pre-service teachers in both groups had "correct" answers. A majority had "partially correct" and "incorrect" answers. This shows that a large number of pre-service teachers did not have a complete conceptual understanding of the science process skills. Of particular interest, the results show that nearly all the pre-service teachers failed to provide correct definitions/explanations for observation, measurement, inferring, formulating models and identifying variables. The analysis of the open-ended responses revealed the following trends in the definitions or explanations provided by the participants: many participants used tautology in defining the terms in almost all categories. Many participants failed to distinguish between predicting and inferring. A number of them used everyday language in defining communication. There was frequent use of the phrase "educated guess" on defining hypothesis, and prediction; many defined observation in terms of senses with the sense of sight being most prevalent; many defined classification on basis of similarities ignoring the differences; and many did not mention measuring tools when defining measurement.

Conceptual understanding by demographics

The results show that there were no significant differences between pre-service teachers' conceptual understanding of science process skills and their demographic variables. That is, this group of pre-service teachers' conceptual understanding was similar regardless of whether: they were enrolled in an introductory or advance science education course, their teaching subject major was science or not, they had taken the integrated science core course or not, they had taken 1-3 or 4-6 university science courses, and whether they were male or female.

Overall conceptual understanding level

Table 4 shows that the overall conceptual understanding of the process skills was not good for both participants in the introductory ad advanced courses. The level of understanding for a majority of the participants ranged between 41 and 60 percent.

Performance on science process skills

As shown in Table 5 below the results show that most of the participants in the introductory course had a very good percentage score on the performance test, with 36.7% of the participants scoring between 81 – 90 percent. A similar trend was found in the advanced science methods course. However, there was a higher percentage of students who scored between 21 – 30 percent in the advanced science methods course (19.4%) than in the introductory course (1.7%).

Performance on individual science process skills

In order to determine how well participants performed on each process skill, test items for each skill were analyzed separately. Table 6 below shows that the participants performed better on the skills of *modeling, predicting, inferring, classification,* and *interpreting data.* To the contrary, they performed most poorly on *experimenting, identifying variables, graphing, communicating, hypothesizing and observing.*

Comparing performance on process skills by demographics

The results in Table 7 show that there were no significant differences between performance and demographic variables. That is, pre-service teachers' performance is similar regardless of whether: they were enrolled in an introductory or advance science education course, their teaching subject major was science or not, they had taken the integrated science core course, they had taken 1-3 or 4-6 university science courses, and whether they were male or female.

Ratings on science process skills for conceptual understanding and performance

Table 8 shows the ratings to highlight the process skills pre-service teachers understood and performed well and poorly. The pre-service teachers exhibited better conceptual understanding of the science process skills in this descending order: *classifying, observing, measuring, predicting, hypothesizing, interpreting data, experimenting, communicating, inferring, identifying variables, modeling and graphing.* With respect to performance, they performed better on the science process skills in this descending order: *modeling, predicting, inferring, classifying, interpreting data, measuring, observing, hypothesizing, communicating, graphing, identifying variables and experimenting.*

Comparing conceptual understanding and performance

The extent of the difference between pre-service teachers' conceptual understanding and performance on science process skills was determined using the t-test. The results showed that there is a statistically significant difference between conceptual understanding and performance, t (180) = -10.050, df = 180, p = 0.000, with performance having a higher mean [M= 31.7, SD= 13.2) than conceptual understanding [M= 17.6, SD = 1.93].

Relationship between conceptual understanding and performance

To determine the relationship between conceptual understanding and performance, a Pearson correlation coefficient was computed. The results showed a low, positive, but non-significant correlation between conceptual understanding and performance, r = 0.050, n = 91, p = 0.637. A positive relationship implies that conceptual understanding is required in order for one to perform on science process skills tasks. However, this relationship is not significant enough to be certain that conceptual understanding and performance are correlated.

DISCUSSION

The purpose of this study was to examine pre-service teachers' conceptual understanding and performance on the science process skills. The results show that pre-service teachers had a poorer conceptual understanding of the science process skills than their performance in the science process skills. The definitions and explanations provided by the participants revealed that they did not have complete conceptual knowledge of the science processes, and had difficulties in defining and explaining processes such as *inferring, communicating, formulating hypothesis, experimenting, formulating models, interpreting data, predicting, identifying variables* and *graphing.* The poor conceptual understanding revealed in this study is consistent with the findings in previous studies (e.g. Emereole, 2009; Farsakoglu, Sahin, Karsli, Akpinar &Ultay, 2008). For example, Emereole (2009) found that pre-service high school science teachers did not have sufficient conceptual understanding of science process skills. Similarly, studies on teachers' understanding of inquiry have reported that teachers teaching different grade levels lack sufficient understanding of science process skills (Lotter, Harwood, & Bonner, 2007; Luft, 2001).

Table 3. Comparison of conceptual understanding between demographics

Demographic		*N*	Mean (SD)	*t*	*df*	*p-value*	*Sig*
Science education course level	Introductory	60	17.5 (1.6)	-0.525	89	0.60	NS
	Advanced	31	17.7 (2.5)				
Teaching subject major	Science	27	17.4 (1.90)	-0.594	89	0.55	NS
	Non-science	64	17.7 (1.95)				
Taken integrated science core course	Yes	60	17.9 (1.96)	1.904	89	0.06	NS
	No	31	17.1 (1.79)				
Number of university science courses taken	1-3 courses	37	17.6 (1.52)	-0.105	89	0.917	NS
	4-6 courses	54	17.6 (2.18)				
Gender	Female	75	17.7 (1.95)	1.360	89	0.177	NS
	Male	16	17.0 (1.75)				

Sig at p<.05; *NS means Non Significant*

Table 4. Percentages on conceptual understanding test

Conceptual understanding range (%)	Pre-service teachers %	
	Introductory course (n=60)	Advanced course (n=31)
0-10	0.0	0.0
11-20	0.0	0.0
21-30	0.0	0.0
31-40	1.7	0.0
41-50	61.7	64.5
51-60	36.7	29.0
61-70	0.0	3.2
71-80	0.0	3.2
81-90	0.0	0.0
91-100	0.0	0.0

Table 5. Percentages on performance test

Performance range (%)	Pre-service teachers %	
	Introductory course (n=60)	Advanced course (n=31)
0-10	0.0	0.0
11-20	3.3	3.2
21-30	1.7	19.4
31-40	6.7	9.7
41-50	3.3	6.5
51-60	1.7	9.7
61-70	10.0	3.2
71-80	16.7	16.1
81-90	36.7	22.6
91-100	20.0	9.7

Table 6. Performance on each process skill

Process Skill	Type of process skill	Number of Test Items	Correct Responses %	
			Introductory course (n=60)	Advanced course (n=31)
Formulating Models	Integrated	2	68	66
Predicting	Basic	3	63	60
Inferring	Basic	3	62	59
Classification	Basic	3	58	59
Interpreting Data	Integrated	3	58	56
Measuring	Basic	4	52	49
Observation	Basic	3	45	43
Hypothesizing	Integrated	5	40	41
Communicating	Basic	3	38	38
Graphing	Integrated	4	22	18
Identifying Variables	Integrated	11	13	10
Experimenting	Integrated	4	10	12

Table 7. Comparison of performance between demographics

Demographic		N	Mean (SD)	t	df	*p-value*	*Sig*
Science methods course	Introductory	60	32.3 (13.8)	0.652	89	0.516	NS
	Advanced	31	30.4 (12.1)				
Teaching subject major	Science	27	29.3 (13.5)	-1.101	89	0.274	NS
	Non-science	64	32.7 (13.1)				
Taken integrated science core course	Yes	60	32.0 (13.4)	0.351	89	0.726	NS
	No	31	31.0 (13.0)				
Number of college science courses taken	1-3 courses	37	31.9 (13.5)	0.141	89	0.888	NS
	4-6 courses	54	31.5 (13.2)				
Gender	Female	75	31.9 (13.2)	0.371	89	0.712	NS
	Male	16	30.5 (13.9)				

Sig at p<.05

Table 8. Ratings on Science Process Skills for Conceptual Understanding & Performance

Rating	Conceptual Understanding	Performance
High Understanding & Performance	Classifying	Modeling
↑	Observing	Predicting
	Measuring	Inferring
	Predicting	Classifying
	Hypothesizing	Interpreting data
	Interpreting data	Measuring
	Experimenting	Observing
	Communicating	Hypothesizing
	Inferring	Communicating
↓	Identifying variables	Graphing
Low Understanding & Performance	Modeling	Identifying variables
	Graphing	Experimenting

In this study, the majority of the pre-service teachers who attempted to provide traditional and correct definitions of classification and experimenting, also included additional incorrect statements - suggesting that some participants just rote-learned the definitions. In this case, it was difficult to determine for sure whether the participants really understood the process skills or not. Similarly, Duit (1984) argues that it is difficult to distinguish whether partially correct definitions and explanations of a concept provided by participants are based on their understanding or merely rote-learned.

With respect to performance, the results showed that pre-service teachers performed better on science process skills compared to their conceptual understanding. A possible explanation for this good performance could be based on the contexts in which performance test items were presented (Song & Black, 1992). The performance test in this study presented these skills in a real-world type situation, which could have assisted the pre-service teachers in solving them because they were familiar with the contexts. Multiple choice questions also allow respondents a greater chance at guessing the right answer. Ideally, we argue that in order for one to be able to apply their knowledge to given situations or scenarios, that individual must at least have some conceptual understanding of a given concept. However, our results did not support this logic – as illustrated by non significant correlation between pre-service teachers' conceptual understanding of and performance on science process skills. Therefore, these pre-service teachers do not possess adequate conceptual understanding of the science process skills despite performing well on the skills test. However, the finding offers some hope in that some pre-service teachers may teach the science process skills because they performed well on the test.

Particularly, the pre-service teachers performed well on the following skills in descending order: *classification, predicting, experimenting*. The skills on which they performed most poorly were *graphing, observation, identifying variables, and measuring*. With respect to *graphing* skill, previous research (e.g. Roth, McGinn, & Bowen, 1998) report that pre-service teachers have graphing difficulties and such difficulties were attributed to a lack of appropriate training in the graphing skills. Other researchers have also found that teachers have difficulties with measurements, especially in science experiments (Rollnick, Lubben, Lotz & Dlamini, 2002).

An interesting finding in this study is on the skills of classification and experimenting. In both conceptual understanding and performance tests, pre-service teachers exhibited highest understanding and performance on these two skills. One possible postulation for this trend is that people in general use classification to sort out things in everyday life chores – thereby enabling these pre-service teachers to do well on this skill. With regard to experimenting, one would argue that pre-service teachers would often hear or talk about experimenting simply because science is technically an "experiment" subject. Therefore, at one point or the other these pre-service teachers have always heard of the word "experiment" and have been required to conduct experiments in their teacher education science courses. All these experiences would have made them more adept at conceptually articulating and performing well on classification and experimenting process skills.

Implications and recommendations

The poor conceptual understanding held by the elementary education pre-service teachers in this study is of great concern and a call to action on the part of science teacher education and professional development programs. As such, we recommend an explicit intervention on science process skills in teacher education programs for pre-service teachers to develop conceptual understanding of the science processes outlined in the national science education reforms and standards. It is also important to inform teacher educators of the fact that even those pre-service teachers who appear to perform well on a performance test may not have adequate understanding of the science processes. Teacher educators should identify pre-service teachers' prior ideas about science processes in science methods courses.

Future research should investigate how pre-service teachers with poor conceptual understanding of science process skills tend to perform better on science process skills performance tests. Studies should also investigate how teachers' good performance on science process skills translates into classroom instruction.

CONCLUSIONS

The elementary education pre-service teachers had very limited conceptual understanding of the science process skills but performed better on science process skills test. Their incorrect definitions of science processes ranged from not having any idea to tautology. Moreover, most participants interchanged definitions of some science processes notably predicting and inferring. As such, there was a gap between their performance on the process skills and their ability to provide reasonable conceptual definitions and explanations of the science process skills. The results suggest that this group of pre-service teachers did not have sufficient conceptual understanding of science process skills to help their future students to understand them in a meaningful way.

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