Identifying Scientific Reasoning Skills of Science Education Students

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Abstract: This article discusses a study carried out to investigate scientific reasoning skills among 82 science pre-service teachers at the Faculty of Education, Universiti Teknologi MARA (UiTM), one of the public universities in Malaysia. Undeniably, the development of general scientific abilities is critical to enable students of science, technology, engineering, and mathematics (STEM) to successfully handle open-ended real-world tasks in their future careers. Teaching goals in STEM education include fostering content knowledge and developing general scientific abilities. One such important ability is scientific reasoning. Scientific reasoning encompasses critical thinking skills as a vital learning outcome in modern science education. Lawson (1978) categorized scientific reasoning into four domains: Conservative Concept, Proportional Concept, Control Variable and Probabilistic Thinking, and Hypothetical-Deductive Reasoning. An instrument by Lawson (1978) was adapted for this study. The findings show that a majority of the science pre-service teachers possess low ability in scientific reasoning. It is also found that there was no significant difference among the science pre-service teachers of the physics, biology and chemistry disciplines when examined. The findings showed that Physics students had developed a higher ability in Conservative Concept, Proportional Concept, and Hypothetical-Deductive Reasoning and chemistry students had a higher ability in Control Variable and Probabilistic Thinking, whereas biology students had a moderate ability in the four scientific reasoning patterns.

Keywords: Scientific Reasoning; Science Education; Higher Education.

1. Introduction

One of the skills which is crucial to science teachers is to be critical and become creative thinkers through the utilization of reasoning skills in an inductive and deductive manner (Curriculum Development Centre, 2005). The Curriculum Development Centre has stressed on the importance of acquiring reasoning ability as it can potentially assist students to think outside the box. Most traditional education settings place the importance of content learning in fostering student reasoning abilities. Furthermore, the past study indicated that scientific reasoning strongly correlates with cognitive abilities as effective science reasoning involves logic, justification, rational thinking and decision making (Lei Bao et. al, 2009).

Scientific reasoning, in general, is a type of reasoning that engages students in hypothesis development, particularly about how things work and then testing those hypotheses. During the reasoning process, individuals tend to associate the investigated phenomena with their prior knowledge and then new knowledge is sought after as the previous knowledge is corrected and integrated. According to Piaget's formal operational stage as cited by Steussy (1984), scientific reasoning is the use of scientific processing skills in order to justify a particular conclusion in scientific inquiry. This process includes the ability to relate the observed phenomena with scientific theory in order to predict possible outcomes. Scientific reasoning is employed within experimental design setting, hypothesis testing and data interpretation. Therefore, scientific reasoning comprises both conceptual understanding and inquiry skills (Zimmerman,

2005) in order to relate the experimental data with theories in producing the best conclusion. Undeniably, scientific reasoning is an important skill in science-related studies as it ensures effective implementation of experiments, hypothesis testing, data analysis and deduction of findings (Committee on Undergraduate Biology Education to Prepare Research Scientists (CUBE), 2003) cited in Schen (2007).

Since cognitive thinking and conceptual thinking are distinctively different, hence, the discussion in this paper is inclined towards reasoning skills with close association with conceptual thinking only. The 82 respondents in the study were chosen from one of the three science-related disciplines: chemistry, biology and physics. These disciplines are inherently different in terms of the scientific concept, contextual and knowledge. Sazali (2007) pointed out that the different disciplines in science will influence students differently particularly in the manner they collect and organize data. This would affect the way students' process information in carrying out their scientific reasoning.

This study focuses on the relationship between the different science disciplines (minor courses in the pre-service teachers' bachelor degree programs) and the patterns of scientific reasoning. It is hoped that this study will provide a significant contribution to the body of knowledge, deepens the understanding of science educators in the way pre-service teachers carry out their scientific reasoning and provides effective recommendations based on the findings derived from the study.

2. Procedure

The present study employed a quantitative research design (Majid & Shamsudin, 2019). A quantitative research design is employed in order to measure the relationship between the minor courses the respondents were enrolled in and their scientific reasoning pattern. Correlation-based study is utilized in enabling the relationships among variables within a group to be determined and allowing for cause and effects to be examined.

The target populations of this study were the science pre-service teachers who were enrolled in their final semester (semester eight) of the four-year bachelor's degree in education program. The sample size was determined through calculation based on formula constructed by Krejcie and Morgan (1970), as shown in Table 1 and Table 2.

Table 1: Sample Distribution

Respondents	**Major Course of Study**			**Total**
	Biology	**Physics**	**Chemistry**	
Population	34	31	32	97
Sample	31	22	29	82

Table 2: Distributions of Students in Different Major Course

	Frequency	**Percent (%)**	**Valid Percent**	**Cumulative Percent**
Biology	31	37.8	37.8	37.8
Physics	22	26.8	26.8	64.6
Chemistry	29	35.4	35.4	100.0
Total	82	100.0	100.0	

A set of questionnaires is used to test students' scientific reasoning ability and pattern. The questionnaire consists of a stand-alone test adopted from Lawson (1978). The test is called Lawson's Classroom Test of Scientific Reasoning (Lawson Test). Scientific reasoning ability of respondents in this study was measured by adding up their total scores in the test. Respondents were classified into a certain level of scientific reasoning ability according to their test scores. The range of distribution marks for different levels of ability is as below:

Table 3: Scoring for Scientific Reasoning Ability

Level of Reasoning Ability	Score
Low	0 - 4
Medium	5 - 8
High	9 - 12

There are four types of scientific reasoning patterns in the Lawson Test. The distribution of scientific reasoning patterns in the test is based on the number of questions, presented in Table 4 below.

Table 4: Types of Reasoning Patterns

Types of Scientific Reasoning Patterns	Number of Question
Pattern 1: Conservational Concept	1, 2, 3, 4
Pattern 2: Proportional Concept	5, 6, 7, 8
Pattern 3: Control Variable and Probabilistic Thinking	9, 11, 13, 15, 17, 19
Pattern 4: Hypothetical-deductive	21, 22, 23, 24

Proportional reasoning is characterized as critical for the learning of algebra and chemistry; on the other hand, probabilistic thinking is identified as crucial for the learning of biology and social science; and controlled variables are critical for conducting experiments in any science-based studies.

3. Findings

The findings indicate that a majority of the science pre-service teachers possessed low scientific reasoning skills.

Table 5: Scientific Reasoning Ability vs Major Courses of Study

	Scientific Reasoning Ability				Total
		Low	Medium	High	
Biology	Count	28	3	0	31
	% of Total	34.1%	3.7%	0.0%	37.8%
Physics	Count	16	6	0	22
	% of Total	19.5%	7.3%	0.0%	26.8%
Chemistry	Count	25	4	0	29
	% of Total	30.5%	4.9%	0.0%	35.4%
Total	Count	69	13	0	82
	% of Total	62.2%	15.9%	0.0%	100%

Low scientific reasoning skills can be discussed in relation to the current education system. Lay (2010) points out that the education system influences logical thinking abilities particularly in a system that places more importance on examination results. With an exam-oriented system, teachers' motivation is directed towards completing the syllabus within the allotted time frame; hence very little attention is given in developing thinking skills. In this study, all students are not provided with sufficient opportunities to explore and generate scientific reasoning.

In addition, students should also be provided with the thinking experiences related to Higher Order Thinking Skills (HOTS) (Chaplin, 2007), which include the three highest levels on the Bloom's Taxonomy of Cognitive Domain namely: analysis, evaluation and create (Anderson & Krathwohl, 2001).

The development of critical thinking skills is not without challenges. In higher education settings, there is a mismatch between the vast topics required completion every semester and the assigned weekly lecture hours. Though efforts were made in inculcating scientific reasoning skills among the pre-service teachers, most of the lectures were still characterized by rote learning and memorization of facts and procedures. In addition, the teaching styles employed by the educators are also limited in the way the pre-service students reasoned and the outcomes of their reasoning. Digital learning programs have been advocated to significantly improve scientific reasoning ability within a short period of time.

Generally pre-service teachers were found having higher reasoning skills in conservative concepts compared to the other three patterns of scientific reasoning (Table 6). This is supported by a study carried out by Lay (2010) which also found that students had higher ability in conservative reasoning. Of the four reasoning patterns investigated, the pre-service teachers were found to score lower in hypothetical-deductive reasoning. The findings contradict Lay's findings who found probabilistic thinking was the lowest reasoning ability of the students.

Of the three science disciplines investigated (physics, chemistry and biology), physics pre-service teachers scored highly in conservative concept, proportional concept and hypothetical-deductive reasoning with high mean of score. Inhelder and Piaget (1958), cited in Kurtz and Korplus (1979), explained that proportional concept is a type of scientific reasoning pattern that involves mathematical calculations of ratio. Compared to chemistry and biology, physics is a discipline that involves the use of more calculation and mathematical concepts. This indirectly helps the development of proportional reasoning among the physics pre-service teachers.

In chemistry, the mean score for controlled variable and probabilistic thinking is highest compared to other pattern types. Chemistry is considered a difficult subject and the most challenging because its learning does not only require students to understand chemical concepts but also to comprehend symbols, terminologies and theories (Chui, 2005).

Table 6: Scientific Reasoning Pattern in Three Major Courses of Study

		Mean	Std. Deviation	95% Confidence Interval for Mean	
				Lower Bound	Upper Bound
Pattern 1	Biology	1.13	0.562	0.92	1.34
	Physics	1.27	0.767	0.93	1.61
	Chemistry	1.14	0.581	0.92	1.36
	Total	1.17	0.625	1.03	1.31
Pattern 2	Biology	0.55	0.768	0.27	0.83
	Physics	0.91	0.868	0.52	1.29
	Chemistry	0.52	0.738	0.24	0.80
	Total	0.63	0.794	0.46	0.81
Pattern 3	Biology	0.87	0.428	0.71	1.03
	Physics	0.86	0.351	0.71	1.02
	Chemistry	0.97	0.421	0.81	1.13
	Total	0.90	0.404	0.81	0.99
Pattern 4	Biology	0.16	0.374	0.02	0.30
	Physics	0.27	0.550	0.03	0.52
	Chemistry	0.17	0.384	0.03	0.32
	Total	0.20	0.429	0.10	0.29

Chemistry learning also involves the understanding of abstract concepts, hence requiring intellectual thinking at a higher level as compared to the learning of biology or physics (Sirhan, 2007). Hence, this influences the indirect development of scientific reasoning in relation to controlled variable and probabilistic thinking among the chemistry pre-service teachers. These pre-service teachers, however, did not score highly in reasoning skills and patterns related to conceptual understanding and critical thinking.

A national survey carried out by Hwang (1994, 1996) cited in Chiu (2005), examining fifth and sixth grade students' conceptions towards chemistry found that students experienced difficulties in differentiating a substance whether it is an acid or a base. Interestingly, teachers were also found to face similar issues. Schmidt (1995), cited in Chiu (2005), carried out a study looking at the development of acids and base concepts has reported that the knowledge of these concepts among 11th, 12th and 13th was weak. Hence, weak grasp of scientific knowledge hinders successful development of scientific reasoning skills and pattern of students. Chu (2005), in his study, concluded that students generally have incomplete, under-developed and flawed structure at various levels of chemistry knowledge.

In the discipline of biology, the pre-service teachers were found to have acquired moderate ability in their pattern of scientific reasoning, given their moderate mean scores. The analyzed data indicated weak ability in the pattern of scientific reasoning. These biology pre-service teachers did not show strong ability in any patterns of reasoning. However, Schen (2007) claimed that the learning of biology requires a high level of scientific reasoning as a result of transference of skills from other science disciplines (physics and chemistry). As indicated earlier, thinking skills and scientific reasoning skills are highly correlated, with the use of one skill would involve the utilization of the other skills. The findings of this study, however, contradicted Schen's statement. The findings revealed that students have demonstrated a higher degree of memorization rather than discerning content through understanding. Obviously, continuous exposure to such thinking processes would result in the development of a low level of conceptual understanding, cognitive thinking skills and the ability to reason effectively.

4. Conclusions

In conclusion, there is no significant relationship between the studied science disciplines and scientific reasoning patterns of the science pre-service teachers. Only pre-service teachers of some of the disciplines were found to demonstrate high ability in a number of scientific reasoning patterns. The study found that the disciplines that the pre-service teachers were enrolled in did not have any influence on their scientific reasoning skills. According to the National Research Council (1996), information processing skills are vital in teacher training programs, particularly so in the teaching of science disciplines. This is because the ability to process information effectively has a positive correlation with the quality of scientific reasoning ability. The high mean scores for physics and chemistry pre-service teachers indicate that they had been trained with scientific information processing skills. In fact, the mastery of scientific information processing skills is crucial in carrying out scientific investigation such as in carrying out experiments and projects. Education system also affects students' ability to reason scientifically and prolonged exposure to memorization of facts and procedural knowledge in teaching would cause the students to develop weak cognitive thinking skills and poor scientific reasoning abilities.

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