PRESERVICE TEACHERS' REASONING ABILITIES AND THEIR RELATIONSHIPS WITH ACHIEVEMENT IN SCIENCE

Bob C S Yong
Sultan Hassanal Bolkiah Institute of Education
Universiti Brunei Darussalam
<chuiseng.yong@ubd.edu.bn>

Abstract
The purpose of this study was to investigate preservice science teachers' reasoning abilities and their relationships with achievement in science. A total of 39 preservice teachers who were enrolled in the Bachelor of Education General Science program participated in the study. Three different sets of tests to determine teachers' ability in abstract, spatial and verbal reasoning were administered to the sample of teachers. The results revealed that a higher percentage of teachers were categorized as medium ability on abstract, spatial and verbal reasoning. There were also statistically positive significant correlations between teachers' reasoning abilities and achievement. On analysis using multiple regression, it was found that spatial and verbal reasoning appeared to be the best predictor for achievement in biology whilst abstract and spatial reasoning to be best predictors for achievement in chemistry and physics respectively. Implications of the findings were discussed.
Key words: preservice teachers, reasoning ability, science achievement.

Introduction

Science is widely recognized as a difficult subject (Cailloids, Gottelmann-Duret & Lewin, 1996; Dalacosta, Kamariotaki-Paparrigopoulou, Palyvos & Spyrellis, 2009; TES, 2005). Many empirical studies have reported that students encountered great difficulties in comprehending the theoretical scientific concepts and principles in biology (Christianson & Fisher, 1999; Friedler, Amir & Tamir, 1987; Moss, 2005), in chemistry (Garnett, Garnett & Hackling, 1995; Griffiths, 1994; Nakhleh, 1992; Saul & Kikas, 2003) and in physics (Linder, 1992; Shayer & Adey, 1981; Williams & Cavallo, 1995).

Indeed the complexities of science concepts also pose serious challenges to teachers in their attempts to impart that knowledge to the students. Like students, teachers had been reported to have serious misunderstanding of some of the science concepts (Çalik & Ayas, 2005; Harlen & Holroyd, 1997; Summer & Kruger, 1992; Yip, 1998). This has a serious repercussion when the wrong concepts are conveyed to the students as a result of teachers' lack of deep understanding of the subject matter knowledge, inaccurate teaching or uncritical use of the science textbooks (Sanders, 1993; Yip, 1996).

An important role of teachers is to interpret and translate complex science concepts to the level appropriate to the learning experiences of the target students. It is essential that they must first develop a personal understanding of the subject matters that they are expected to impart to their students. When teachers do not fully understand the content of science well they will not be able teach it well (Abd-El-Khalick & Lederman, 2000) and even more damaging they may cause students' alternative conceptions (Ginns & Watters, 1995; Quiles-Pardo & Solaz-Portoles, 1995). Inevitably, how well science is taught will depend on the teachers' understanding of the continuity and connections of concepts in science and their ability to relate these concepts to everyday life (Ball, 2000; Borko & Putman, 1996). McNeill and Krajcik (2008) reported that the extent to which teachers' use instructional practices such as modeling scientific explanation, making the rationale of scientific explanation explicit, defining scientific explanation, and connecting scientific explanation to everyday explanation greatly influence students' learning of scientific explanations.

While a considerable body of research exists focusing on the role of reasoning ability on students' achievement in science (BouJaoude, Salloum & Khalick, 2004; Cavallo, 1996; Yenimez, Sungur & Tekkaya, 2006; Yilmaz & Alp, 2006), relatively little is known about science teachers' reasoning ability and performance. As no studies have been done on teachers' abilities that are related to abstract, spatial and verbal reasoning, the author decided to embark on this area of research. It is believed that the data generated from this study will provide invaluable information on preservice teachers' cognitive ability. The following questions guided the present study:

1. What are preservice teachers' abilities in abstract, spatial and verbal reasoning?
2. What are the distributions of preservice teachers categorized as low, medium and high ability on abstract, spatial and verbal reasoning?
3. Are the mean achievement scores for preservice teachers with different reasoning abilities the same or different in science?
4. Are there any relationships between preservice teachers' reasoning abilities and their achievement in science?

Methodology

Sample

Altogether 39 preservice teachers who were enrolled in the Bachelor of Education General Science programme participated in the study. The sample consisted of first- and second-year cohorts. Of the total sample, 11 were males and 28 were females.

Instruments

Preservice teachers' mental abilities were measured using the abstract, spatial and verbal reasoning ability tests. The tests were adapted from the psychometric tests and the details are explained in an earlier study by Yong (2007).

Procedure

Tests were administered during one of the lecture periods. These were conducted by the author himself when he first met the teachers in the first semester when they started the course. Before the test, the teachers were given an answer sheet in which they have to write their full name and sex. They were also told that their identity would be kept secret. The three tests were given consecutively and no extra time was given to any of the tests. Teachers responded each item by circulating either A, B, C, or D in the answer sheet.

Achievement

Achievements in science were based on their written exam results taken at the end of the first and second semesters of the first year courses. The marks that they obtained for biology in two semesters were added and then averaged. The same was done for chemistry and physics. For analysis of achievement, the marks obtained were recorded as weighed scores.

Results and Discussion

Reliability of the Instrument

Cronbach's alpha coefficients were calculated by spit-half method to estimate the internal consistency. Value obtained for abstract reasoning test was 0.78, spatial reasoning test was 0.88 and verbal reasoning test was 0.71 indicating that the instrument was considered suitable for the purpose of the study.

Reasoning Abilities of Preservice Teachers

Preservice teachers' abstract, spatial and verbal reasoning abilities were analysed using descriptive statistics and the total means for each of the reasoning abilities were summarized in Table 1. The total mean obtained for abstract, spatial and verbal reasoning ability was 5.15, 7.08 and 11.59 respectively. The results seemed to suggest that a large proportion of teachers in this sample of study were classified as medium ability in abstract, spatial and verbal reasoning.

Results based on the item means indicated that this group of teachers seemed to have better ability in spatial (ranked 1) than verbal (ranked 2) or abstract (ranked 3) reasoning.

Table 1
Means and Standard Deviations for different Reasoning Ability Tests

Reasoning	Items	Total Mean	SD	Item Mean	Rank
Abstract	10	5.15	1.81	0.51	3
Spatial	10	7.08	1.48	0.71	1
Verbal	20	11.59	2.92	0.58	2

N=39

Preservice Teachers classified as Low, Medium and High Reasoning Ability

In classifying teachers into low, medium and high ability in the three reasoning ability tests, results showed that in abstract reasoning test, 20.5% of the teachers were identified as low ability whilst 71.8% and 7.7% were identified as medium and high ability respectively (Table 2). In the case of spatial reasoning, no teachers were classified as low ability (0%) whilst 61.5% and 38.5% were classified as medium ability and high ability respectively. With respect to verbal reasoning, results showed that no teachers were classified as low ability (0%), 74.4% were classified medium ability and 25.6% were classified as high ability. A higher percentage of teachers were classified as high ability in spatial reasoning than in verbal and abstract reasoning.

Table 2
Percentage of Teachers in Different Levels of Reasoning Ability

	Teachers (%)		
Reasoning	Low	Medium	High
Abstract	20.5	71.8	7.7
Spatial	0	61.5	38.5
Verbal	0	74.4	25.6

N = 39

Achievement in Science of Preservice Teachers

Preservice teachers' achievement in science were analysed from the marks that they obtained in the semesters 1 and 2 exams. Results in Table 3 indicated that teachers' achievement in chemistry (mean = 69.87) was the highest followed by biology (mean = 59.89) and physics (mean = 54.49). This was also reflected in the grades as a higher percentage of teachers obtained superior grades A and B in chemistry (60.5%) compared with biology (15.8%) and physics (21.0%).

Table 3
Grades obtained by Preservice Teachers in Biology, Chemistry and Physics expressed in terms of Percentages

	Grade (% teachers)						Mean	
Subject	A	B	C	D	E	F	(% exam)	SD
Biology	2.5	12.8	30.8	30.8	20.5	2.5	59.89	10.04
Chemistry	23.7	36.8	15.8	13.2	10.5	0	69.87	13.78
Physics	2.6	18.4	21.1	15.8	21.1	21.1	54.49	15.49

N = 39

Associations between Achievement in Science and Reasoning Abilities

Pearson product-moment correlation coefficients were calculated to find out the relationships between reasoning abilities and science achievement. The results showed that there were positive

significant associations between reasoning abilities and science achievement (Table 4). More specifically, biology achievement was positively correlated with spatial and verbal reasoning abilities, whilst chemistry achievement was correlated with abstract reasoning ability and physics achievement with spatial reasoning ability.

Table 4
Correlations between Reasoning Abilities and Achievement in Science

	Reasoning Ability		
Subject	Abstract	Spatial	Verbal
Biology	0.15	0.52**	0.32*
Chemistry	0.36*	0.15	-0.01
Physics	0.25	0.47*	0.29

*p<0.05; **p<0.01; N=39

Students' achievement in science in relation to their reasoning ability was analysed using one-way ANOVA. For biology, the *F* values obtained showed that there are significant differences between achievement and level of ability for spatial and verbal reasoning (Table 5). Teachers categorized as high ability in spatial and verbal reasoning scored higher marks than those categorized as medium ability. In other words, achievement in biology is very much affected by teachers' spatial and verbal reasoning abilities and not at all by their abstract reasoning ability.

Table 5
Teachers' Achievement in Biology in Relation to Different Levels of Reasoning Ability

	Low		Medium		High		
Reasoning	Mean	SD	Mean	SD	Mean	SD	*F*
Abstract	57.50	6.23	60.61	10.83	54.33	11.06	1.05
Spatial	0		57.54	10.29	62.60	9.09	3.22*
Verbal	0		57.72	10.07	64.60	8.42	6.46*

*p<0.05

Table 6
Teachers' Achievement in Chemistry in Relation to Different Levels of Reasoning Ability

	Low		Medium		High		
Reasoning	Mean	SD	Mean	SD	Mean	SD	*F*
Abstract	66.00	19.87	72.32	14.33	86.00	2.83	2.41*
Spatial	0		70.75	15.08	73.36	16.89	0.17
Verbal	0		71.86	14.48	71.22	19.75	2.43

*p<0.05

In the case of chemistry, the *F* values showed there is a significant difference between achievement and level of ability for abstract reasoning (Table 6). Teachers categorized as high ability in abstract reasoning scored higher marks than those categorized as medium and low ability. It seemed that achievement in chemistry is very much affected by teachers' verbal reasoning ability and not at all by their spatial and verbal reasoning abilities. For physics, teachers who were categorized as high ability in spatial reasoning scored significantly higher marks than those categorized as medium ability (Table 7). Hence, achievement in physics is very much affected by teachers' spatial reasoning ability and not at all by their abstract and verbal reasoning abilities.

Table 7
Teachers' Achievement in Physics in Relation to Different Levels of Reasoning Ability

	Low		Medium		High		
Reasoning	Mean	SD	Mean	SD	Mean	SD	*F*
Abstract	47.40	10.14	59.06	15.62	57.00	0	1.22
Spatial	0		49.77	14.28	64.54	11.58	2.42*
Verbal	0		54.95	14.60	62.60	15.96	1.05

*$p<0.05$

Multiple correlation analysis was employed to investigate the associations between reasoning abilities and teachers' achievement in science. The results were presented in Table 8. The multiple R value for biology was 0.54, chemistry was 0.37 and physics was 0.50. This indicated that the percentage achievement variance for biology was 29%, chemistry was 13% and physics was 25%. Furthermore, standard regression coefficients *(Ⓑ)* obtained indicated that spatial and verbal reasoning abilities showed positive significant associations with biology achievement (Table 8). This suggests that these reasoning abilities contribute to the prediction of achievement scores with spatial ability found to be the more important than verbal ability. Thus, it can be explained that as teachers' ability in spatial and verbal reasoning increases, their achievement in biology also increases.

Table 8
Relationships between Reasoning Abilities and Achievement of Science in terms of Standard Regression Coefficients (Ⓑ)

	Standard Regression Coefficients (Ⓑ)		
	Biology	Chemistry	Physics
Abstract		0.36*	
Spatial	0.51**		0.55*
Verbal	0.14*		
Multiple R	0.54**	0.37*	0.50*
R^2	0.29	0.13	0.25

*$p<0.05$; **$p<0.01$

For chemistry, standard regression coefficients *(Ⓑ)* obtained indicated that abstract reasoning ability showed positive significant associations with achievement. Thus, it appeared that achievement in chemistry is very much affected by teachers' abstract reasoning ability. For physics, standard regression coefficients *(Ⓑ)* obtained indicated that spatial reasoning ability showed positive significant associations with achievement. Thus, it can be explained that achievement in physics is related to teachers' ability in spatial reasoning.

Conclusion and Implications

The present study investigated preservice teachers' abstract, spatial and verbal reasoning abilities and their relationships with achievement in science. Findings of the study revealed that preservice teachers have a higher ability on spatial reasoning than abstract and verbal reasoning. Furthermore, there were significant differences between preservice teachers' performance in science and their ability in abstract, spatial and verbal reasoning. More specifically, biology achievement was positively correlated with spatial and verbal reasoning abilities. Teachers at the high ability level of spatial and verbal reasoning performed significant better than those at the medium ability level. The possible explanation may be lie with biology texts which are highly descriptive in nature (Amimbola & Baba, 1996; Hill, 1986) and hence require higher language proficiency to read than other natural sciences. In a study, Gustin and Corazza (1994) reported

that verbal reasoning was found to be the strongest predictor of biology achievement and they reasoned that success in biology tends to require more reading than chemistry and physics. The relationship between spatial ability and academic success in biology was also observed by Stump (1994) who explained that many problems in learning biology such as visualizing the structure of complex molecules in biology has spatial implications. The findings of the present study revealed that teachers who have a higher level of spatial and verbal reasoning ability will have a better chance of scientifically develop and understand complex biology concepts. The ability to meaningfully grasp the concepts of biology would mean that they will be in a better position to impart those concepts clearly and accurately to the students.

In chemistry, achievement was correlated with abstract reasoning ability and teachers at the high level of abstract reasoning were found to perform significantly better than those at the medium and low ability. Many chemistry concepts are highly abstract entities and many chemistry problems require application of chemical principles and application of functional relationships among concepts (Ertepinar, 1995). The use of symbolic representations in expressing complex concepts and principles requires students to be a strong abstract thinker (Szesze, 2002). Çalik and Ayas (2005) reported that student teachers had difficulty grasping the concepts of chemical bonding, distribution of solute and solvent, and intermolecular forces in a gaseous medium. They suggested that teaching abstract concepts should use strategies such as models, analogies and role-playing that would provide some concrete examples to help better understanding of these phenomena.

In physics, Bertoline (1998) explained that many of the fundamental concepts are so unique that they often require the construction of active mental models of their physical and mathematics models in the mind of the learners. He affirmed that learning of physics phenomena like spring force, electro-static force and gravitation requires spatial cognition. In the present study, it seemed that preservice teachers at the high level of spatial reasoning ability achieved better than those at the medium level of ability further attests the importance of spatial reasoning in learning physics.

Given the mental cognition that these preservice teachers possess, they will have the capacity to process and understand complex abstract science concepts quickly, thus significantly increases their confidence in teaching science. As Gess-Newsome (1999) asserted that teachers must have a deeper understanding of content that can be accessed flexibly and efficiently for the purpose of instruction, only then they are able to teach science in a conceptually rich and accurate manner. In the light of evidence discerned from this study, the present preservice teachers will be more likely to have the inherent ability to teach science effectively and develop students' intellectual and thinking skills related to science systemically. This will depart from science teaching that is often based on rote learning and theoretical exercises and one that is seldom linked to the developing of thinking skills related to solving real problems commonly observed in science classrooms (Caillods, Göttelmann-Duret & Lewin, (1996). The present group of preservice teachers will be articulated and fluent in verbal skills, highly creative and have high ability to grasp new ideas and assimilate new information which are the essential attributes of teachers of science.

This preliminary study has generated some interesting findings on the influence of reasoning abilities on science achievement. Much work needs to be done and ideally with a larger sample of preservice teachers so that a clearer pattern of the relationship between their reasoning ability and understanding of complex scientific concepts and principles can be delineated from these more in-depth studies. More interesting and perhaps more important is a follow-up study of this group of preservice teachers when they become fully qualified teachers to examine carefully their teaching practices in terms of their ability to interpret and present complex abstract science concepts to students. Additionally, it will also be interesting to assess how well students learn science under the guidance of teachers who possess different level of reasoning ability. Many questions remain such as: 'Will teachers with high reasoning ability produce better student

achievement in science than those with low reasoning ability?' 'Are teachers with high reasoning ability able to explain complex science concepts more explicitly than those with low reasoning ability?' 'Are the teaching approaches different between teachers with different reasoning ability in terms of rote learning and inquiry learning?' Attempts to tackle these related areas could prove exciting in future work.

References

Abd-El-Khalick, F. & Lederman, N.G. (2000). Improving science teachers' conception of the nature of science: A critical review of the literature. *International Journal of Science Education, 22,* 665-701.

Abimbola, I.O. & Baba, S. (1996). Misconceptions and alternative conceptions in science textbooks: The role of teachers as filters. *The American Biology Teachers, 58*(1), 14-19.

Ball, D.L. (2000). Bridging practices: Intertwining content and pedagogy in teaching and learning to teach. *Journal of Teacher Education, 51*(3), 241-247.

Bertoline, G.R. (1998). Visual science: An emerging discipline. *In Journal for Geometry and Graphics, 2*(2), 181-187.

Borko, H. & Putman, R. (1996). *Learning to teach.* In D. Berliner & R. Calfee (Eds.), Handbook of educational psychology (pp.673-725). New York: Macmillan.

BouJaoude, S.B., Salloum, S. & Khalick, F. (2004). Relationships between selective cognitive variables and students' ability to solve chemistry problems. *International Journal of Science Education, 26,* 63-84.

Cailloids, F., Göttelmann-Duret, G. & Lewin, K. (1996). *Science education and development: Planning and policy issues at secondary level* (pp. 24-88). Paris: Pergamon.

Çalik, M. & Ayas, A. (2005). A comparison of level of understanding of eighth-grade students and science student teachers related to selected chemistry concepts. *Journal of Research in Science Teaching, 42*(6), 638-667.

Cavallo, A.M.L. (1996). Meaningful learning, reasoning ability, and students' understanding and problem solving of topics in genetics. *Journal of Research in Science Teaching, 33,* 625-656.

Christianson, R.G. & Fisher, K.M. (1999). Comparison of student learning about diffusion and osmosis in constructivist and traditional classroom. *International Journal of Science Education, 21*(6), 687-698.

Dalacosta, K., Kamariotaki-Paparrigopoulou, M., Palyvos, J.A. & Spyrellis, N. (2009). Multimedia application with animated cartoons for teaching science in elementary education. *Computer & Education, 52*(4), 741-748.

Ertepinar, H. (1995). The relationship between formal reasoning ability, computer assisted instruction, and chemistry achievement. *Hacettepe Üniversites Égitim Fakultesi Dergisi, 11,* 21-24.

Friedler, Y., Amir, R. & Tamir, R. (1987). High school students' difficulties in understanding osmosis. *International Journal of Science Education, 9*(5), 541-551.

Garnett, P.J., Garnett, P.J. & Hackling, M.W. (1995). Students' alternative conceptions in chemistry: A review of research and implications for teaching and learning. *Studies in Science Education, 25,* 65-95.

Gess-Newsome, J. (1999). *Pedagogical content knowledge: An introduction and orientation.* In J. Gess-Newsome, & N. Leberman (Eds.), Examining pedagogical content knowledge (pp. 3-17). United States: Kluwer-Academic Publishers.

Ginns, I.S. & Watters, J.J. (1995). An analysis of scientific understanding of pre-service elementary teacher education students. *Journal of Research in Science Teaching, 32,* 205-222.

Griffiths, A.K. (1994). A critical analysis and synthesis of research on students' chemistry misconceptions. In H. J. Schmidt (Ed.), *Problem solving and misconceptions in chemistry and physics* (pp. 70-99). Hong Kong.

Gustin, W.C. & Corazza, L. (1994). Mathematical and verbal reasoning as predictors of science achievement. *Roeper Review, 16*(3), 160-162.

Harlen, W. & Holroyd, C. (1997). Primary teachers' understanding of concepts of science: impact on confidence and teaching. *International Journal of Science Education, 19*(1), 93-105.

Hill, L. (1986). Teaching and the theory and practice of biology. *Journal of Biological Education, 20*(2), 112-116.

Linder, C.J. (1992). Is teacher-reflected epistemology a source of conceptual difficulties in physics? *International Journal of Science Education, 14*(1), 111-121.

McNeill, K.L. & Krajcik, J. (2008). Scientific explanations: Characterizing and evaluating the effects of teachers' instructional practices on student learning. *Journal of Research in Science Teaching, 45*(1), 53-78.

Moss bin Mat Juni (2005). *Upper secondary students' conceptions and misconceptions of diffusion and osmosis.* Unpublished MEd dissertation, Universiti Brunei Darussalam

Nakhleh, M.B. (1992). Why some students don't learn chemistry. *Journal of Chemical Education, 69,* 191-196.

Quiles-Pardo, J. & Solaz-Portoles, J.J. (1995). Students and teachers misapplication of Le Chatelier's Principle: implications for the teaching of chemical equilibrium. *Journal of Research in Science Teaching, 32*, 939-957.

Sanders, M. (1993). Erroneous ideas about respiration: The teacher factor. *Journal of Research in Science Teaching, 30,* 919-934.

Saul, H. & Kikas, E. (2003). Difficulties in acquiring theoretical concepts: A case of high-school chemistry, *TRAMES, 7*(57/52), 2, 99-119.

Shayer, M. & Adey, P. (1981). *Towards a science for science teaching.* London: Heinemann.

Stump, H. (1994). *Subskills of spatial ability and their relationships to success in accelerated mathematics courses.* In K.A. Heller & E.A. Hany (Eds.), Competence and responsibility: The Third European Conference of the European Councils for Higher Ability (pp. 286-297). Seattle, WA: Hogrefe and Huber.

Szesze, M.J. (2002). Science teaching strategies using symbols, icons and abstract representations:Available:http://www.mcps.k12md.us/curriculum/science/instr/scistrasymbols.htm. Cited on 14.11.2006

Summer, M. & Kruger, C. (1992). Research into English primary school teachers' understanding of concepts of energy. *Evaluation and Research in Education, 6,* 95-111.

TES (2005). How to fire enthusiasm of future biologists. *Time Educational Supplement, Issue 4163,* p. 21.

Williams, K.A. & Cavallo, A.M.L. (1995), Reasoning ability, meaningful learning, and students' understanding of physics concepts. *Journal of College Science Teaching, 5,* 311-315.

Yenilmez, A., Sungur, S., & Tekkaya, C. (2006). Students' achievement in relation to reasoning ability, prior knowledge and gender. *Research in Science & Technology Education, 24*(1), 129-138.

Yilmaz, A. & Alp, E. (2006). Students' understanding of matter: The effect of reasoning ability and grade level. *Chemistry Education Research and Practice, 7*(1), 22-31.

Yip, D.Y. (1996). Misconceptions of biology teachers and the implication for teacher education programmes. Paper presented at the International Conference on Basic Education, Hong Kong.

Yip, D.Y. (1998). Teachers' misconceptions of the circulatory system. *Journal of Biological Education, 32*(3), 207215.

Yong, B.C.S. (2007). Relationship between reasoning abilities and students' achievement in science: a case study. *Journal of Applied Research in Education, 11*, 108-119.