The development of views on the nature of science of learners in a science enrichment programme

VM Baloyi[1], WE Meyer[1] and E Gaigher[2]

[1]Department of Physics, University of Pretoria, Private bag X20, Hatfield, Pretoria, South Africa, 0028, South Africa
[2] Department of Science, Mathematics and Technology Education, University of Pretoria, Private bag X20, Hatfield, Pretoria, South Africa, 0028

E-mail: vonani.baloyi@up.ac.za

Abstract. This paper presents results of the study conducted with a group of 82 grade 10 applicants to a science enrichment programme offered by a university in South Africa. The Views on the Nature of Science (VNOS) questionnaire composed of eleven open-ended questions was used in examining learners' views on seven aspects of the nature of science (NOS). A follow up study was performed on the same group of learners two years later. This group included learners that had attended the science enrichment course (the experimental group) as well as the learners that had not done so (the control group). This study provided the opportunity to investigate the effect of attending the science enrichment course on the learners' views on the NOS. The follow-up study showed that the view on NOS of both groups improved over the period. Although the score in the VNOS test of both groups improved, the improvement for the experimental group was statistically significant. In addition, the results in the post test also differed by a statistically significant amount between the two groups. Interestingly, the understanding of the social and cultural embeddedness, did not improve in either the control or the experimental group.

1. Introduction

The understanding of the nature of science (NOS) is an important part of scientific literacy [1, 2, 3]. Abd-El-Khalick and Boujaoude [4] argue that a scientifically literate person should develop an understanding of science concepts and the relationship between science and technology. Other research studies show that the teaching of NOS from elementary through post-secondary science education improves students' enjoyment of science; interest in science classes and careers; curiosity in learning about science [5].

Many learners in different parts of the world have poor conceptions of NOS [6]. Research shows that effective teaching of NOS cannot be accomplished as the majority of science teachers in the United States (US) are harbouring uninformed conceptions of NOS [7]. This may be related to teacher-centred instruction methods which teachers have developed from their own experiences as students [8].

In many South African schools, teacher-centred instruction occurs, which does not promote the development of a better understanding of different features of NOS [9]. After the 1994 first democratic elections, the government's reconstruction and development programme led to the introduction of new Curriculum 2005 (C2005) policy guided by principles of outcomes-based education [10] in 1998, which was later reviewed to become the Revised National Curriculum Statement for General and

Education Training (Grades R- 9) and the National Curriculum Statement for grades 10 – 12 [11]. Further curriculum review led to the National Curriculum Assessment Policy Statement [12] which still promoted the development of science process skills, application of scientific knowledge in real-life problems and acknowledging the relationship between science, society and technology [12].

The current study was undertaken at a South African university that hosts a science enrichment programme for senior secondary school pupils. The enrichment programme, presented by the Faculty of Natural and Agricultural Sciences, uses an inquiry based approach in a three year programme from grade 10 to 12 to help learners develop a better understanding and appreciation of science. During the programme, the students visit the University on one Saturday every month during the school semester and for a week during the July holiday. In the first year of the programme, learners are exposed to the various departments in the faculty and participate in inquiry-based activities which provide them with hands-on opportunities to learn and experience science. During the second year, the learners are assigned to a specific department, where they participate in a project lead by senior students and staff from that department. The aim of the project is to allow students to experience what scientists really do, how research is done and showing the various opportunities that exists in the various sciences. The activities varied widely between departments, but were generally hands on mini-research projects, not directly related to the work done at school, but rather extending the work to new aspects that are not part of the standard school curriculum. In some cases the projects included aspects of actual research done in the department. The NOS was not explicitly taught during the programme.

Every year, schools in the area are invited to nominate up to two candidates for the programme. From these, approximately 50 learners are selected on the basis of their grade 9 marks as well as a short essay they have to write on why they enjoy science. Measures are also in place to ensure that the group was well balanced as far socio-cultural background gender is concerned, and generally only one student per school was selected.

This study reports on the development of the understanding of NOS amongst a cohort of participants in the enrichment programme and compares their performance with that of a group of their peers, which were proposed, but not selected for the programme.

1.1. Inquiry based learning

Inquiry has been defined diversely across the literature. Broadly, it may be defined as scientific investigations that encourage classroom practices such as posing questions which focus at knowledge attainment and development [13]. The inquiry-based approach to science education has recently been extended by the Next Generation Science Standards in the USA at high school level, to include interdisciplinary inquiry in teaching [14). Learning through inquiry enables students to construct their own knowledge by building connections between their existing knowledge and new experiences [15].

1.2. Nature of science

Nature of science (NOS) is a construct used by many researchers to refer to epistemological beliefs in science education. NOS focuses on the philosophical assumptions that underpin science knowledge [16] such as values, improvement, theoretical developments, how agreements are reached within the scientific community, and the distinctive features of scientific knowledge. This study will be informed by Lederman's [17] description of NOS as the epistemology of science or science as a way of knowing. The differences which have been and are still occurring among the historians of science, philosophers of science, scientists and science educators with regard to the specific definition of NOS are irrelevant to high school learners [18]. In addition, there is a level of consensus on features of NOS that can be accessible to high school learners [19]. The seven NOS aspects include that scientific knowledge is tentative; empirical; theory-laden; requires imagination and creativity; influenced by social and cultural values; based on observation and inferences; and described by scientific theories and laws and developed in the absence of a universal scientific method.

Table 1. Questions in the modified VNOS form C questionnaire

Nr	Text
2	What in your view is science? What makes science (or a scientific discipline such as physics, biology, etc) different from other disciplines of inquiry (e.g. religion, philosophy)? [Empirical and tentative nature]
3	What is an experiment? [Empirical nature]
4	Does the development of scientific knowledge require experiments? Give an example to explain your position. [Empirical and tentative nature]
5	After scientists have developed a scientific theory (e.g. atomic theory, evolution theory), does the theory ever change? • If you believe that scientific theories do not change, explain why. Illustrate your answer with examples. • If you believe that scientific theories do change: (a) Explain why theories change? (b) Explain why we bother to learn scientific theories? Illustrate your answer with examples. [Tentative nature]
6	Is there a difference between a scientific theory and a scientific law? Illustrate your answer with an example. [Difference between theory and law.]
7	Science textbooks often represent the atom as a central nucleus composed of protons (positively charged particles) and neutrons (neutral particles) with electrons (negatively charged particles) orbiting that nucleus. How certain are scientists about the structure of the atom? What specific evidence do you think scientists used to determine what an atom looks like? [Theory and law, scientific models]
8	It is believed that about 65 million years ago the dinosaurs became extinct. A number of hypotheses were formulated by scientists to explain the extinction. • A: One hypothesis, formulated by one group of scientists, suggests that a huge meteorite hit the earth 65 million years ago and led to a series of events that caused the extinction. • B: Another hypothesis, formulated by another group of scientists, suggests that massive and violent volcanic eruptions were responsible for the extinction. How are these different conclusions possible if scientists in both groups have access to and use the same set of data to derive their conclusions? [Observations and inferences, tentative nature, imagination and creativity.]
9	Some people claim that science is infused with social and cultural values. That is, science reflects the social and political values, philosophical assumptions, and intellectual norms of the culture in which it is practised. Others claim that science is universal. That is, science transcends national and cultural boundaries and is not affected by social, political, and philosophical values, and intellectual norms of the culture in which it is practiced. • If you believe that science reflects social and cultural values, explain why. Illustrate your answer with examples. • If you believe that science is universal, explain why. Illustrate your answer with examples. [Social and cultural embeddedness].
10	Scientists perform experiments/investigations when trying to find answers to the questions they set for themselves. Do scientists use their creativity and imagination during their investigations? • If yes, then at which of the three stages of the investigations do you believe scientists use their imagination and creativity: (i) planning and design, (ii) data collection, (iii) after data collection? Please explain why scientists use imagination and creativity. Provide examples if you can. • If you believe that scientists do not use their imagination and creativity, please explain why. Provide examples if you can. [Imagination and creativity].
11	A person interested in botany collected specimens from Table Mountain and from the Drakensberg. Based on their specimens and his extensive field notes, he developed the concept of altitudinal zonation, which describes how plant species found at sea level differ significantly from those found at high elevations. Would you describe this person's work as science? Please explain. [Scientific method].
12	You decide to inventory the birdhouses in your neighbourhood as an after-school project. During this inventory, you locate a total of 34 birdhouses, only 14 of which are being used by nesting birds. The others are currently unoccupied. You decide that you would like to know why some of the birdhouses are occupied and others are not. How would you conduct this study? [Scientific method]

2. Methodology

The study is located in the positivist paradigm, using a mixed methods approach. For this study learners' views of NOS were assessed using a modified open-ended Views of the Nature of Science (VNOS Form C) questionnaire adapted from Lederman et al. [20]. The questionnaire contains eleven open-ended questions that examine the aforementioned aspects of the NOS, summarized in Table 1. The VNOS Form C questionnaire has been validated and used regularly in research [20], and minor adaptations were made to make it more relevant to South African learners. Learners wrote pre- and post-tests and follow up interviews were conducted to validate the data found through the open-ended questionnaire [17]. The response to each question was scored on a scale of 0 to 4 (0 represents naïve, 1 represents partially naïve, 2 represents moderate, 3 represents partially informed, 4 represents informed) and results analysed quantitatively. Descriptions of NOS aspects by Schwartz, Lederman and Crawford [21] were used as a guide during the scoring process. In this study, qualitative data was transformed into quantitative data, followed by the analysis of the final data [22].

The pre-test was performed before the students were informed of the outcome of the selection process, but was only evaluated afterwards. The post test was performed during the university's open day, where participants were invited and offered a meal voucher. The entire group of applicants to the university's science enrichment program was evaluated. Of these, 82 learners consisting of thirty-two males and fifty females wrote both the pre and the post test. Only these students were included in this study.

At the beginning of the study, the participants in this study were minors with an age range of between 14 and 16, therefore parents and legal guardians gave written consent for their children to participate in this study and results published anonymously. Participation in the study was voluntarily and participants were free to withdraw at any time. Permission was granted by the ethics committee of the university prior to the commencement of this study.

3. Results

Figure 1 shows the VNOS scores obtained for each question by the control and experimental groups at the start of the study (a) and at the end of the study (b). At the start of the study, for most questions, there was no significant difference between the scores obtained by the control and experimental groups. A possible exception is Q4 ("Are experiments required", where the control group did 40% worse, however, according to a t-test, the difference is not statistically significant (p = 0.10). The average score of the control group was 5% lower than that of the experimental group (p = 0.22). We can therefore conclude that, even though the experimental group was selected on merit from the group of applicants, there was no significant difference between the scores obtained in the VNOS test by the two groups before the study.

Figure 1(b) shows the VNOS scores for the control and experimental groups per question, as

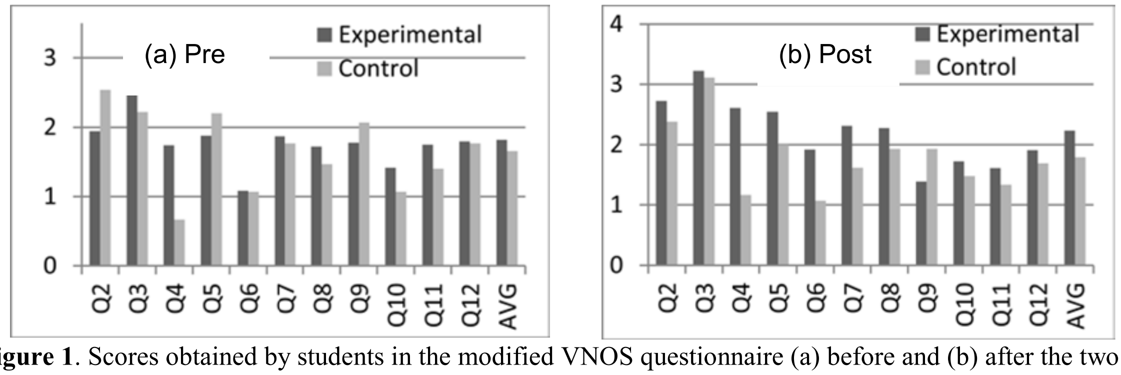

Figure 1. Scores obtained by students in the modified VNOS questionnaire (a) before and (b) after the two year period.

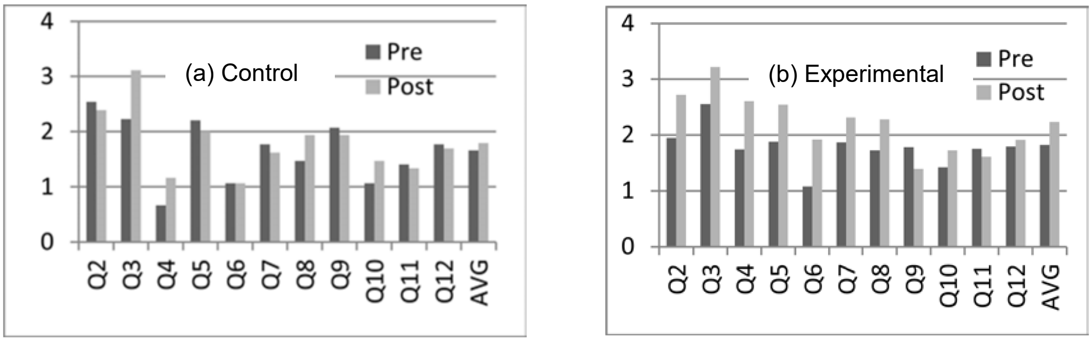

Figure 2. Scores obtained by students in the modified VNOS questionnaire for (a) the control (left) and (b) the experimental (right) groups in the pre- and post-tests.

obtained after the study. In all but one question (Q9, Social and cultural influence) the experimental group scored better than the control group. In Q9, the control group scored 14% better, but this was not statistically significant ($p = 0.27$). The experimental group scored considerably better in Q4 ("Are experiments required", 36%, $p = 0.01$), and the average score was 11% better ($p = 0.03$).

Figure 2 shows average VNOS scores for the experimental and control groups obtained in the pre- and post-tests. As seen in Figure 2(a), the control group showed improved scores in 4 questions and reduced scores for 6 questions, none of which were statistically significant. The average score improved by 4%, but again this was not statistically significant ($p = 0.58$). For the experimental group, the increase in the average score was significant (13%, $p = 0.002$). The scores in 9 questions improved and only two scores decreased. For question 2 the improvement was statistically significant ($p = 0.004$), while the improvement in questions 3, 4, 6 and 7 was substantial with $p = 0.04$, 0.02, 0.01, 0.01, respectively). Again Q9 was the notable exception to the rule.

4. Discussion

From the results of the pre-test, it seems that there was no statistical significant difference between the control and the experimental group. This was expected, as the selection process did not deliberately select students on the basis of their knowledge of NOS. We can therefore assume that the control and experimental groups were approximately equal at the start of the study, and that any differences in the groups at the end of the study could be attributed to the experimental group's participation in the science enrichment programme.

The control group showed no significant improvement in their VNOS scores after two years. However, the experimental group showed a statistically significant improvement, and, in the post test, scored better than the control group in all but one question, with a statistically significant (11%, $p = 0.03$) higher average score. This is strong evidence that the science enrichment programme contributed significantly to the participant's understanding of NOS. Specifically the students showed a strong improvement in their understanding of the empirical and tentative nature, the difference between theories and laws, as well between observations and inferences. Interestingly, there was a decrease in both groups understanding that science is embedded in social and cultural background. Although not statistically significant, this aspect could be worth while investigating further.

The significant improvement in the average VNOS score of the experimental group compared to the control was unexpected, as NOS was not explicitly taught. Implicit approaches are believed not to encourage students to reflect on science activities thus they cannot develop informed views of NOS [7, 23]. The finding in the current study differs from that of Bell et al. [24] in that there were students in the experimental group who showed significantly more informed views of NOS.

5. Conclusion

We conclude that the participation of the grade 10 learners in the science enrichment programme enhanced their understanding of the nature of science, even though NOS was not explicitly taught. As far as individual aspects are concerned, the largest effect was observed in the answers to the question "are experiments required". A possible exception was the learners' understanding of the social and cultural embeddedness of science, in which a slight decrease was observed. Given the wide variety of cultural backgrounds of learners in South Africa, this point may be worth further investigation.

The results in the current study should not be generalized to the entire grade 10 population of South Africa, as only the best students from each school participated.

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References
[1] Anderson R D 2007 Inquiry as an organizing theme for science curricula *Handbook of Research on Science Education* ed KS Abell and NG Lederman (Mahwah, NJ: Lawrence ErlbaumAssociates, Inc) pp.807-830
[2] Roberts D A 2007 Scientific literacy *Handbook of research on science education* ed KS Abell and NG Lederman (Mahwah, NJ: Lawrence Erlbaum Associates, Inc) pp.729-780
[3] Lederman N G 2007 Nature of science: Past, present, and future *Handbook of research on science education* ed KS Abell and NG Lederman (Mahwah, NJ: Lawrence Erlbaum Associates, Inc) pp. 831-880
[4] Abd -El-Khacik F and Boujaoude S 1997 *J. Research Sci. Teach.* **34** 673
[5] Clough M P 2011 *Sci. Teach.* **78** 56
[6] Abd-El-Khalick F 2006 Over and over again: College students' views of Nature of Science *Scientific Inquiry and Nature of Science: Implications for Teaching, Learning and Teacher Education* ed LB Flick and NG Lederman (Dordrecht, The Netherlands: Springer)
[7] Abd-El-Khalick F and Lederman N G 2000 *Int. J. Sci. Educ.* **22** 665
[8] McDermott L C, Shaffer P S and Constantinou C P 2000 *Phys. Educ*. **35** 411
[9] Dekkers P 2006 *Afr. J. Math. Sci. Tech. Educ.* **10** 81
[10] Department of Education 2002 *Revised National Curriculum Statement* (Pretoria: Government Printer)
[11] Department of Education 2006 *National Curriculum Statement* (Pretoria: Government Printer)
[12] Department of Education 2012 Curriculum and Assessment Policy Statement: Physical Sciences Grade 10 – 12 (Pretoria: Government Printer)
[13] Blanchard M R, Annetta L A and Southerland S A 2008 *Investigating the effectiveness of inquiry-based versus traditional science teaching methods in middle and high school laboratory settings* Paper presented at the annual conference of the National Association for Research in Science Teaching, Baltimore, MA.
[14] National Research Council 2012 *A Framework for K-12 Science Education Practices, Crosscutting Concepts, and Core Ideas* (Washington, DC: National Academy Press)
[15] Berge O and Slotta J D 2005 *Learning technology standards and inquiry-based learning* Paper presented at the meeting of the Information Science and IT Education Joint Conference, Arizona.
[16] Smith C and Wenk L 2006 *J. Res. Sci. Teach.* **43** 747
[17] Lederman N G 1992 *J. Res. Sci. Teach.* **29** 331
[18] Abd-El-Khalick F and Lederman N G 2000 *J. Res. Sci. Teach.* **37** 1057
[19] Abd-El-Khalick F, Bell L and Lederman N G 1998 *Sci. Educ.* **82** 417
[20] Lederman N G, Abd-El-Khalick F, Bell R L and Schwartz R S 2002 *J. Res. Sci. Teach.* **39** 497
[21] Schwartz R S, Lederman N G and Crawford B A 2004 *Sci. Educ.* **88** 610
[22] Caracelli V J and Greene J C 1993 *Educ. Eval. Policy Anal.* **15** 195
[23] Akerson V L and Abd-El-Khalick F 2003 *J. Res. Sci. Teach.***40** 1025
[24] Bell R, Blair L, Crawford B and Lederman N G 2003 *J. Res. Sci. Teach.***40** 487