# Effect of guided inquiry laboratory activities on first-year physics students' views on the nature of science

**V M Baloyi[1], W E Meyer[1] and E Gaigher[2]**
[1] Department of Physics, University of Pretoria, Private bag X20, Hatfield, Pretoria, South Africa, 0028
[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 study investigated the effect of 'explicit reflective guided inquiry' (ERGI) versus traditional recipe-based laboratory practical activities on first-year university students´ views on the nature of science (NOS). The ERGI laboratory activities adopted the 'Physics by Inquiry model'. Ninety seven first-year Bachelor of Science physics students participated in this study at a well-established South African university, which compared guided inquiry and traditional recipe-based laboratory approaches. The students were divided randomly in a control group that did traditional recipe-based practical activities and an experimental group, that did guided inquiry-based practical activities. Both groups had the same reflective questions on an aspect of the NOS at the end of the practical activities. At the end of the practical course, data were collected using the VNOS-Form C questionnaire and follow-up focus group interviews were conducted. Additionally, there was also a practical test that consisted of both a hands-on and a written section. The results showed that the experimental group students developed better understanding of three aspects of NOS: tentative, empirical and difference between observations and inferences. However, students' conceptions on the difference between theory and law, role of imagination and creativity, influence of social and cultural values and notion of using universal scientific method in the development of knowledge were similar for the two groups. This study demonstrated that there is significant effect of guided inquiry-based laboratory practical activities on the students' understanding of NOS in first-year physics course compared to traditional laboratory approach.

## 1. Introduction

This study is informed by the goals of the Introductory Physics Laboratory of the American Association of Physics Teachers and the National Curriculum Assessment Policy Statement (1- 4) which encourage Inquiry-Based Science Education (IBSE) which is believed to enhance the deep understanding of nature of science (NOS), scientific inquiry (SI) process skills and science literacy [5]. NOS and SI are different constructs but they are intertwined with regard to the goals of current science education [6]. Teaching students how to conduct SI engages students in the practices of science including conducting scientific investigations and performing laboratory practical activities like scientists to address questions and formulate explanations using creative and critical thinking [3]. When students are engaged in scientific investigations and practical activities, they use observations and inferences to formulate conclusions and empirically based explanations [7]. Understanding of the difference between observations and inferences, informed conceptions of the tentativeness, subjectivity, difference between theory and law, and role of social and cultural values associated with the development of scientific knowledge are aspects of NOS [8] which are also linked with conceptions about SI [6].

The current study was undertaken at a South African university where the laboratory component of an undergraduate physics course has been redesigned from a traditional to an inquiry-based format. The rationale behind this transformation is that the current practice of doing the practical laboratory activities is procedural [9] which, according to experience, does not enhance students' thinking skills [10]. Conversely, the ERGI laboratory activities may bring about changes in students' thinking and problem-solving skills [11]. It is believed that asking intellectually guiding questions in inquiry-based activities directs students' thinking and helps a teacher to understand their thinking [12]. Here the ERGI laboratory activities served as a context to the NOS questions [13].

Socrates used questioning in teaching to assist a student to think, analyse and seek for new information [14]. Such questioning may assist the development of understanding NOS, which is considered as knowledge that needs to be understood rather than to be known [15]. This study has explored the degree to which explicit-reflective questions integrated with the ERGI laboratory activities, as suggested by Clough [15], influence the students' views on NOS. Explicit-reflective instruction includes: focusing students' attention to targeted NOS aspects through discussion and written work, encouraging students to both think about how their investigations are linked to the NOS features and how their ERGI laboratory activities resemble the work of scientists [16]. We investigate if students may develop a better understanding of targeted NOS aspects when they are combined with physics content to be learnt in the ERGI laboratory activities [6]. These correlations have not yet been experimentally studied in the South African context, where students are traditionally taught via a recipe-based method. The results of this study may enhance the understanding of current science laboratory practices, learning processes and the potential effects of inquiry-based instruction at university level.

Inquiry has a wide range of overlapping meanings among different scholars. Inquiry is broadly defined as scientific investigations that encourage classroom practices such as posing questions which focus at knowledge attainment and development [17]. IBSE originated from the deep conceptualisation of the scientific practice and processes [18]. The fundamental principles of IBSE include discovering natural laws, relating information into real-life contexts, developing critical thinking, and encouraging positive attitudes towards science learning [19]. The four levels of inquiry include: confirmation, structured, open, and guided inquiry [20], which were formulated to guide teachers in scaffolding students' inquiry activities. This study is informed by Physics by Inquiry model (PbI) in which students' learning is facilitated by guiding questions and the teaching approach utilised is guided inquiry [21]. In PbI, students are guided through step-by-step questions and activities and make observations which they may use to formulate their models in physical sciences. The purpose of questioning encourages the development of thinking and reasoning skills in students [21]. Our research question for this study was: *To what extent does explicitly reflective guided inquiry-based instruction in practical laboratory activities influence first-year Physics students' views on the nature of science?*

## 2. Literature review

A previous study examined metacognition as means to increase the effectiveness of inquiry-based science education [22]. The results demonstrated that metacognitive reflection integrated with inquiry had an effect in the teaching of scientific process and scientific thought and resulted in preparing students to be better critical thinkers and more scientifically literate. Another study explored the effect of reflective discussions following inquiry-based laboratory activities on students' views of NOS [23]. Results indicated that the inquiry-based laboratory activities enhanced students' views of the targeted NOS aspects more than implicit inquiry-based instruction.

The explicit–reflective approach has been used in professional development programs and has enriched practicing elementary teachers' views of NOS [24]. It was demonstrated that after using explicit reflective instruction in inquiry-based context, elementary students developed informed views of NOS [25]. Vhurumuku [26] examined the influence of a short explicit-reflective NOS course on undergraduate science students. The participants' views changed from naïve to reasonably informed. Another study explored the effects of a semester-long NOS course on two teachers' conceptions of NOS using the discursive approach which drew from History, Philosophy and the Sociology of Science [27]. The results showed that teachers' views of NOS changed from inadequate to informed. Abd-El-Khalick's [28] exploratory and interpretive study examined: (a) the influence of an explicit reflective activity-based approach implemented in the context of a science content course, (b) the ability of participants to apply the acquired NOS. The results showed that participants were able to translate NOS understandings in the context of atomic structure covered in the course to that in dinosaur extinction.

Research on gender differences shows that boys' experiences in science and mathematics are different from those of girls throughout their life, which causes confusion and low confidence among girls [29]. Additionally, from an early age, girls show a lower level of interest in physics as compared to their male counterparts. One study tracked the performance differences across gender differences of learners from grade 8 [30]. The results showed an increase in performance differences between males and females. Usually the average early yearly increase of males for academic performance is always greater than that of females. In the tenth grade female learners' attitudes toward science learning start to increasingly become negative [31]. Research shows that by the end of the fifth grade, girls usually show less interest in many areas of physics than boys [32] due to other factors such as teacher behaviour and traditional gender stereotypes [33].

Another study on gender differences regarding academic performance shows that females have better learning vocabulary, grammar, and writing skills than males [34]. It is believed that stereotypical beliefs relating to sex roles and social expectations may have encouraged females to have more positive attitudes towards languages and reading [35]. Conversely, males outperform females in standardised tests in physics because they have better spatial skills. These results have been attributed to higher numerical and spatial abilities of boys [36], coupled with social expectations for boys to have positive attitudes toward science and mathematics [35].

## 3. Methodology

The current study followed an experimental design using a mixed methods approach [37], located within the positivism paradigm. Positivism allowed us to explore the cause and effect of ERGI laboratory activities on students' views on the NOS [25].Convenience sampling was used as the study intended to examine the effect of the ERGI laboratory activities at a specific university on students' views on the NOS [37]. Participation was voluntary and students could withdraw at any time. The population was comprised of 220 first year BSc students. Of these, only, 97 students consented to participate in the study and were randomly assigned to either experimental or control groups [37]. The experimental group did the ERGI laboratory activities designed using PbI [21]. The control group did the traditional recipe-based laboratory activities. Students in both groups worked in small groups and the intervention programme comprised eight weekly practical sessions.

The VNOS-Form C questionnaire [9] was used to evaluate students' views on NOS at the end of the practical course. Collected data was analysed using the guidelines in Lederman, Abd-El-Khalick, Bell and Schwartz [9]. The description frame for NOS aspects by Bell, Lederman and Abd-El-Khalick [38] was used as analysis criteria. A scoring scale used to evaluate students' responses: A score of 1 represented naïve views, 2 represented mixed views and 3 represented informed views of NOS. Focus group interviews were used to validate findings from the questionnaire [9]. VNOS data were sorted randomly and analysed by three researchers to establish reliability [9]. Qualitative data was translated into scores that were analysed quantitatively using descriptive statistics [39]. Numerical test scores of open-ended VNOS questionnaire of both the experimental and control groups were added to obtain an average score per individual. Scores were also statistically analysed and compared.

**4. Results and discussions**

Figure 1 shows the students' scores per NOS aspect, for the control and experimental groups. The students in the experimental group performed slightly better than students in the control group in all the aspects of NOS. However, in no category was the difference between the two groups statistically significant, but the overall (average) score did show a significant difference ($p$ = 0.006). We attribute the difference in VNOS score to the ERGI laboratory activities which guided students in the discovery of science knowledge. For example, at the end of the alternating current practical activity, students were asked the following explicit reflective question: *In this experiment, you were guided by the practical notes. Do you think that all scientists use one scientific method when developing scientific knowledge?* One student (V26) gave the following informed view: *No they use different methods according to their different ways of thinking and analysing their practical notes or other scientific practical notes.* This finding agrees with previous research that revealed that explicit-reflective instruction is more effective than implicit instruction in enhancing learners' views of the NOS [13].

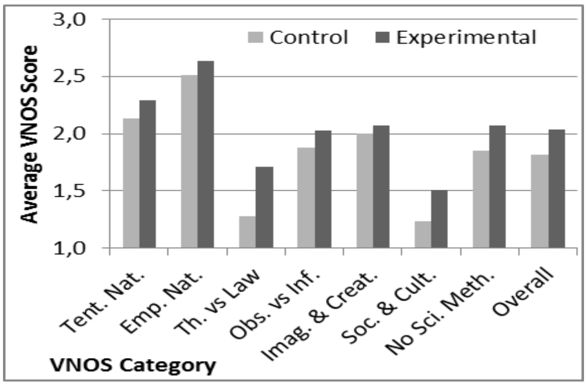


**Figure 1:** Students' VNOS score averages on seven aspects of NOS.

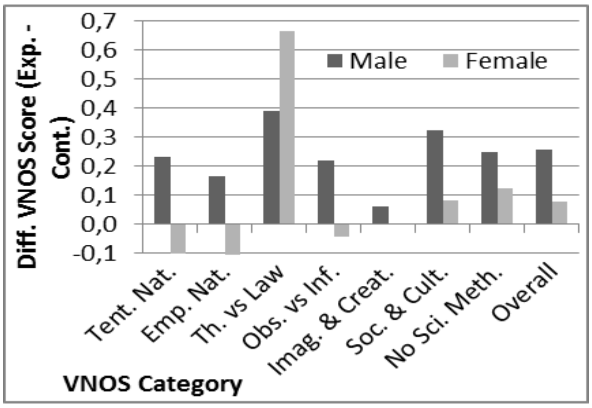


**Figure 2:** Difference between experimental and control groups' VNOS scores, shown separately for males and females

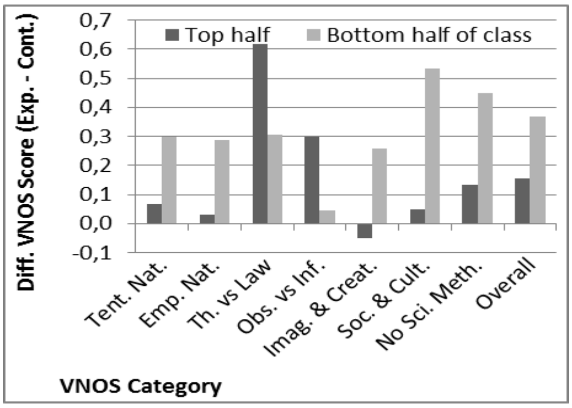


**Figure 3:** Difference between experimental and control groups' VNOS scores, shown separately for the top and bottom halves of the sample.

Figure 2 shows the male and female students' scores per NOS aspect, expressed as the difference between scores of the experimental and the control groups. Generally, males seemed to have benefited most from the ERGI laboratory activities, with overall scores significantly better for the experimental group ($p$ = 0.006) while the benefit in females was not significant ($p$ = 0.3). In all categories, with the exception of understanding the difference between theory versus law, the males benefited more from the ERGI laboratory activities. This agrees with a previous study [40], where inquiry-based laboratory activities were also found to be differentially effective for males and females. Gender differences in academic performance have been reported to be linked with science skills and other factors associated with learning experiences [41]. Research shows that males are more interested in fixing objects, building models, and searching for action-oriented activities while females prefer life science activities comprising the development and caring of plants and animals [42]. Additionally, research has shown that gender differences with regard to academic performance start to increase throughout the secondary school [43]. We ascribe the significant enhancement in the understanding of the difference between theories and laws by the females to the above-mentioned finding that females are generally better with language skills, and would therefore better understand the difference in semantics.

Figures 3 compares the academic top and bottom half of the sample across the NOS aspects. The vertical axis indicates the difference between the scores of the experimental and the control group. Overall, the top half did not show a significant effect ($p$ = 0.33) while the bottom half did show a strong effect ($p$ = 0.01). In all categories, except for the difference between theory and law, the bottom half of class showed a much stronger effect than the top half of the class. The bottom half (low performing students) showed a significant effect on the understanding of social and cultural values ($p$ = 0.03) and in the understanding of scientific methods ($p$ = 0.02). We believe that this difference in performance might be ascribed to the guided inquiry questions being aimed at the academically poorer performers. This was done to ensure that most students would be able to perform the practical activities. High performers could foresee the answers, and therefore benefitted less from the guiding of their thought processes. The exception to the rule was the understanding of the difference between theories and laws, which is, as mentioned earlier, a more complex concept, and therefore it was grasped better by the higher performers.

The findings in this study show that many students had incomplete understanding of NOS. Many students did not understand the difference between theory and law and the role of social and cultural values, but understood the tentative and empirical nature of science. Many students showed an informed view that scientists are not certain of the atomic model and that it might change in the light of further discoveries. For example, during the focus group interviews student (V8) expressed the following informed view: *Scientists have refined their model of the atom over many years. At the moment scientists are quite sure that the model explains the known data. The alpha back scattering experiment was used to find that the atom consisted of a positively charged nucleus and negative particles far away from the nucleus.* The ERGI laboratory activities showed a positive effect on all NOS aspects, especially the two weakest points, i.e. understanding the difference between theory and law and the social and cultural embeddedness. Generally, the males seem to have benefited more than females from the ERGI laboratory activities, with the exception of understanding the difference between theory and law, where female students did much better. Academically weaker students seem to have benefited more from the ERGI laboratory activities than high performing students with the exception of theory and law, and observation and inferences. These results are consistent with the findings in other studies: [13, 22, 23, 26, and 28].

The results of this study should not be generalized to all first year undergraduate Physics courses as the entrance requirements and also the type of Physics courses may have different essence and motivation at different institutions. However, results could be generalized within the population of first-year physics students in the university from which the sample was drawn. It may be concluded that the experimental group showed better understanding in all NOS aspects and statistically significant difference overall than the control group under conditions where reflection was part of practical content. Evidence-based insight into first-year physics students' views on the NOS may help in transforming undergraduate science courses and may contribute to faculty and researchers' understanding of the perceptions of science held by undergraduates, assisting university lecturers to improve scientific literacy in future scientists and diverse university graduates.

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