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Influence of guided inquiry-based laboratory activities on outcomes achieved in first-year physics

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2017

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Influence of guided inquiry-based laboratory activities on outcomes achieved in first-year physics

by

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Submitted in partial fulfilment of the requirements for the degree

Philosophiae Doctor

in the Faculty of Education

University of Pretoria

June 2017

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Declaration

I, Vonani Michael Baloyi, declare that the thesis, which I hereby submit for the degree Philosophiae Doctor at the University of Pretoria, is my own work and has not previously been submitted by me for a degree at this or any other tertiary institution

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INVESTIGATORS	Vonani Michael Baloyi
DEPARTMENT	Science, Mathematics and Technology Education
APPROVAL TO COMMENCE STUDY	04 July 2014
DATE OF CLEARANCE CERTIFICATE	09 November 2016

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Summary

In this study, the effect of 'explicit reflective guided inquiry' (ERGI) laboratory practical activities on first-year physics students' understanding of nature of science (NOS) and academic performance is investigated. Ninety seven students participated in the study and were systematically assigned to the control group that did recipe-based practical activities and the experimental group that did ERGI laboratory practical activities. Both groups had to answer the same explicit reflective questions on an aspect of NOS at the end of each practical session. Data were collected using the VNOS Form-C questionnaire, focus group interviews, explicit reflective questions, combined practical and theoretical year-end examinations. Using blind scoring, students' views were classified as informed, mixed or naïve for each aspect of NOS. The percentage of informed views was larger for the experimental group in each of the seven NOS aspects. Overall, the percentage informed views in the experimental group was larger by a statistically significant margin of 10 percentage points (p = 0.008). The largest differences were observed in the tentative nature of science, the distinction between theory and law, and the role of imagination and creativity. Additionally, males showed more informed NOS understandings than females, while low achieving students were better informed than high achievers, but the differences were not statistically significant. The experimental group did not perform any better than the control group in the practical and theoretical year-end examinations. Therefore, this study demonstrated that ERGI laboratory practical activities activities enhanced first-year physics students' understanding of NOS but not their academic performance.

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Dedication

I dedicate my dissertation work to God the creator of everything in the universe, my family and friends at the University of Pretoria. First, I would like to thank God, for protection, encouragement and instilling strength and wisdom to complete this doctoral degree. I also dedicate this work to my loving and supporting wife, Amukelani Evelyn Baloyi, and my four children, Nyiko, Buyelo, Vonani Junior and Mikhongelo. Without your support and perseverance, this dissertation would have never been written. I would like to thank you Amukelani, for not only helping me keep focus when the writing did not come as easily, but also for taking care of the family while I was busy with my studies. Although I will never be able to express how big the role you played in the attainment of this dissertation, I intend to spend the rest of our lifetimes trying to display my gratitude. I also thank the group of students who have travelled the road toward a doctoral degree with me. Especially the students who volunteered to work whole heartedly as laboratory assistants in the newly introduced guided inquiry physics laboratory practical activities at the Department of Physics. Your insights into the practical course made each class illuminating, and working with all of you on various practical activities has provided me with the experience and knowledge needed to be successful in academia. To those of you who have completed, I look forward to the day we will reunite at conferences and gatherings. To those of you who continue to write, let me tell you the secret that has led to my success, I quote Nelson Mandela, "*The greatest glory in living lies not in never falling, but in rising every time we fall*".

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Acknowledgements

I wish to thank my supervisors who helped to generate this dissertation with their expertise and time. Special thanks to Prof Max Braun, Prof Walter Meyer and Dr Estelle Gaigher, for the number of hours they spent reflecting, refining, reading, and answering variety of questions from a novice researcher. The mentorship you have provided over the last five years has given me a tremendous amount of insight into the academic life, and for this I will not be able to thank you enough. The financial assistance and support of the Sasol Inzalo Foundation, is also gratefully acknowledged. I would also like to thank Prof Chris Theron, Prof Walter Meyer, and Mr Johan Janse van Rensburg for agreeing to serve on the committee that permitted me to do a practical course in the Department of Physics within the Faculty of Natural and Agricultural Sciences. I would also like to thank Dr Marien Graham and the National Research Foundation for the financial support during the last year of this study, as well as helping with statistical analysis of data. I appreciate all people for the effort you have shown in the development of this dissertation. The amount of knowledge I have gained from my time as a novice researcher has been immense, but still is never enough. The friends I have made throughout my time in the university are dear to me and a constant source of inspiration. I would especially like to thank the Department of Physics as a whole at the University of Pretoria. You are all amazing colleagues, and although you do not hear it enough – you do make a difference! Finally I would like to thank the Dean of the Faculty of Natural and Agricultural Sciences Prof Jean Lubuma, the deputy Dean Prof Marietjie Potgieter, the head of Department of Physics Prof Chris Theron, Dr Marietjie Vosloo (Sasol Inzalo Foundation) and fellow students that assisted me with this project. Your endless support is highly appreciated.

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List of abbreviations

AAAS	American Association for the Advancement of Science
AAPT	American Association for Physics Teachers
AC	Alternating current
C	Control group
CCM	Conceptual Change Model
CIR	Direct Current Circuits
CUR	Current Balance
E	Experimental group
EKS	Exponential Decay
EN	Empirical Nature
ERGI	Explicit Reflective Guided Inquiry
ERQs	Explicit Reflective questions
FC	Female students in the control group
FE	Female students in the experimental group
FGI	Focus group interviews
GI	Guided inquiry
HC	Academically high achieving students in the control group
HE	Academically high achieving students in the experimental group
HRASE	History, Relationships, Application, Speculation and Explanation
IBSE	Inquiry Based Science Education
IC	Role of imagination and creativity in science
LC	Academically low achieving students in the control group
LE	Academically low achieving students in the experimental group
MC	Male students in the control group
ME	Male students in the experimental
NCAPS	National Curriculum Assessment Policy Statement
NGSS	Next Generation Science Standards
NOS	Nature of Science
NRC	National Research Council
NSES	National Science Education Standards
NSTA	National Science Teachers Association
OI	Difference between observation and inference
PbI	Physics by Inquiry
PBL	Problem Based Learning
PET	Physics and Everyday Thinking
PP	Percentage points
RC	Discharging Capacitor
RNCS	Revised National Curriculum Statement
SC	Influence of social and cultural values in science
SI	Scientific Inquiry
SM	No single scientific method
STEM	Science, Technology, Engineering and Mathematics
TL	Distinction between theory and law
TN	Tentative nature of science
TR	Transformer
UP	University of Pretoria
US	United States
VNOS	Views on the Nature of Science
ZPD	Zone of Proximal Development

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Chapter 1: Introduction

In this chapter, some background information to the study and a short introduction to inquiry-based teaching are given. In science education communities, inquiry-based learning is often seen as the recommended method that should be used to teach physics (Abd-El-Khalick, Boujaoude, Duschl, Lederman, Mamlok-Naaman, Hofstein, Niaz, Treagust & Tuan, 2004). It is believed that inquiry-based instruction may promote the understanding of the nature of science and scientific inquiry skills as advocated by Feynman (1998), the National Research Council (NRC, 2012) and the Next Generation Science Standards (NGSS) Consortium of Lead States, (2013). Emphasis on inquiry-based instruction has recently been included as an objective in the teaching strategy of the Department of Physics within the Faculty of Agricultural and Natural Sciences, at the University of Pretoria (UP). The Department of Physics has redesigned the laboratory component of physics practical activities from a traditional format into inquiry-based instruction. This was done with the intention of enhancing learning during practical laboratory activities and improving the scientific literacy of physics students. Scientific literacy requires students to understand the nature of science and scientific enquiry (Roberts, 2007). The purpose of this study is to investigate the effects of the Explicit Reflective Guided Inquiry (ERGI) laboratory activities on student outcomes.

1.1 Background

Reforms towards inquiry-based science education in many countries have followed the lead set by the National Research Council (NRC) and American Association for the Advancement of Science (AAAS) in the United States of America. These two organisations have contributed to science education reforms by publishing reports such as the National Science Education Standards, (1996); Science for All Americans, (1990) and Benchmarks for Science Literacy, (1993). The reform documents encouraged an inquiry-based approach which is believed to enhance conceptualisation of the nature of science (NOS), inquiry process skills and science literacy. Pine, Aschbacher, Roth, Jones, McPhee, Martin, Phelps, Kyle, and Foley (2006, p.468), have claimed that inquiry is integral to science research: “Beginning in the 17th century, when Galileo rolled balls down ramps, scientific research has been based on inquiry experimental investigations that attempt to answer questions about the natural world”. Cognitive psychologists (Barron, Schwartz, Vye, Moore, Petrosino, Zech, Bransford & The Cognition and Technology Group at Vanderbilt, 1998; Bransford, Brown & Cocking, 1999; Vosniadou & Brewer, 1992) and education researchers (Hake, 1998; McDermott, 1991; McDermott & Redish, 1999; Redish, 2003) have agreed, after conducting extensive research studies, that active engagement in learning is essential for sustained conceptual understanding. In other words, inquiry attained a prominent role at policy level since it is believed to promote a better understanding of the science content and the application of knowledge in solving real-life situations (Blanchard, Southerland & Granger, 2008).

In spite of the persistent dialogue and efforts related to science education reforms, current science curricula in the United States and many other countries have been unsuccessful in

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teaching students science literacy in order to become successful science learners (Linn, Davis, & Bell, 2004). Research shows that the majority of teachers and students possess naïve views about certain features of NOS (Abd-El-Khalick, 2006; Bell, Blair, Crawford & Lederman, 2003; Abd-El-Khalick & BouJaoude, 2003; Bora & Cakiroglu, 2006; Duschl, 1990; Lederman, 1992). Researchers argue that the teaching of NOS is ineffective because most science teachers in the United States (US) are harbouring uninformed conceptions of NOS (Abd-El-Khalick, Bell, & Lederman, 1998; Abd-El-Khalick & Lederman, 2000a; Lederman, 1992). Lederman (2007) posits that various studies have shown that misconceptions regarding NOS are widespread among high school students, college students and teachers. This may be related to teacher-centred instruction methods which teachers have developed from their own experiences as students (Clark & Peterson, 1986; Nespor, 1987; Pajares, 1992; Richardson, 1996; Shulman, 2006; van Driel, Verloop & de Vos, 1998).

The current teaching approaches in many school science curricula still promote the philosophical mind-set of the 20th century (Bencze & Hodson, 1999). Many teachers, scientists and curriculum developers are not willing to provide students with an opportunity to explore their own problems (Abrams, 1998). The NRC (2000, p. 17) reported “teachers were still using traditional, didactic methods” and “students were mastering disconnected facts in lieu of broader understandings, critical reasoning, and problem-solving skills.” According to Bartholomew, Osborne, and Ratcliffe (2004), teachers fail to recognise that gaining an understanding of the scientific processes and practices is essentially a reflective effort. Additionally, teachers should take the lead in identifying and emphasising crucial features of the scientific practices and processes and eventually students should be able to recognise the processes themselves. However, this cannot easily happen considering that many teachers have inadequate experience with scientific inquiry (Blanchard *et al.*, 2008) and are harbouring naïve conceptions of the process by which scientific knowledge is developed (Anderson, 2007). A comprehensive discussion of barriers to implementation of inquiry and NOS follows later.

Although NOS and scientific inquiry are different constructs, they are closely connected with the aims of current science education. Teaching students to conduct scientific inquiry comprises of teachers involving students in the scientific practices. The scientific practices include conducting scientific investigations and performing laboratory based practical activities like scientists to address questions and formulate explanations using creative and critical thinking (NRC, 2012). When scientists and students are engaged in scientific investigations and practical activities, they use observations and inferences to formulate conclusions and empirical based explanations (AAAS, 1989). Understandings of the difference between observations and inferences as well as informed conceptions of the tentativeness, subjectivity, distinction between theory and law, and role of social and cultural values associated with the construction of scientific knowledge are aspects of NOS. The aspects of NOS are also related to the understanding of scientific inquiry. Allowing students to conduct scientific investigations and practical activities is believed to provide an environment for reflection on NOS aspects, although participating in inquiry only may not promote students’ informed views of NOS (Schwartz *et al.*, 2004).

In addition, the National Commission on Mathematics and Science Teaching for the 21st Century (2000, p.4) reports “children are losing the ability to respond not just to the challenges already presented by the 21st century but to its potential as well”. These reports clearly demonstrate that today’s students should develop a new set of survival skills for the 21st century (Kozma & Schank, 1998). Students should be prepared for a rapidly changing

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world by first learning how to interrogate their ideas and how to use and apply acquired knowledge to solve problems in a new context (Wiske, Franz & Breit, 2005). Secondly, students should learn how to search for large amounts of information using different tools, create new data, analyse and interpret data, draw conclusions and communicate ideas (Kozma *et al.*, 1998). The NRC (2000, p. 6) states that,

> *"The Standards seek to promote curriculum, instruction, and assessment models that enable teachers to build on children's natural, human inquisitiveness. In this way, teachers can help all their students understand science as a human endeavour, acquire the scientific knowledge and thinking skills important in everyday life and, if their students so choose, in pursuing a scientific career".*

The NRC (1996) advocates the significance of scientific inquiry and shows the links between scientific inquiry and real-life. Individuals should be able to participate sensibly in public debates about scientific and technological issues that affect their daily lives. In work places, there is an increasing significance of scientific inquiry because of a demand of advanced skills that requires individuals to study, reason, think critically and creatively, formulate decisions and solve problems. Subsequently, understanding of scientific inquiry contributes to the development of these skills. Currently, the Organisation for Economic Co-operation and Development (OECD) encourages students to enter Science, Technology, Engineering and Mathematics (STEM) careers (NRC, 2005) to enhance the acquisition of skills for the 21st century workforce.

1.2 Reforms in South African's science education system

Science education reforms also occurred in South Africa after the first democratic elections in 1994. The Curriculum 2005 policy which had been guided by principles of outcomes-based-education and learner-centred education was established in 1998 (Department of Education, 2002). The Curriculum 2005 policy appeared to have good intentions of redressing the past differences in education. However, teachers did not have the essential skills and understanding to implement it (Department of Education, 2005a). This has resulted in several curriculum reviews leading to the Revised National Curriculum Statement (RNCS) in 2002 (Department of Education, 2006). Later the RNCS was further transformed into the National Curriculum Assessment Policy Statement (NCAPS) (Department of Basic Education, 2011) in 2011.

The thrust behind science education reforms in South Africa has been to attain scientific literacy for all its citizens (Chisholm & Leyendecker, 2008). The emphasis was on the development of students' conception of scientific knowledge, scientific inquiry and NOS (Department of Education, 2002). In addition, the introduction of scientific processes (planning, conducting investigations, collecting data and interpreting it) in the practical work was encouraged. Similarly, the new current NCAPS still endorses the underlying principles of the RNCS (e.g. development of scientific literacy by conducting scientific investigations). According to the Department of Education (2012, p.8) the grade 10 to 12 Physical Sciences' aims are;

> *"The purpose of Physical Sciences is to equip learners with investigating skills relating to physical and chemical phenomena, for example, lightning and solubility. Examples of some of the skills that are relevant for the study of*

Physical Sciences are classifying, communicating, measuring, designing an investigation, drawing and evaluating conclusions, formulating models, hypothesising, identifying and controlling variables, inferring, observing and comparing, interpreting, predicting, problem-solving and reflective skills.

Physical Sciences promote knowledge and skills in scientific inquiry and problem-solving, the construction and application of scientific and technological knowledge, an understanding of the nature of science and its relationships to technology, society and the environment".

In the South African context, teachers mostly use the traditional lecture method in their science teaching. The traditional lecture method is often perceived as the status quo in the learning environment, a teaching approach that is still being used and has been used for many years (Hamm; Cullen & Ciaravino, 2013). Teachers seldom use inquiry-based teaching since the curriculum is examination oriented. Learners from different grades usually write common examinations at the end of the year. Grade 12 learners, for instance, write examinations set and prepared by the National Department of Education. The use of standardised testing, in South African schools, promotes the belief that students should be taught knowledge instead of discovering knowledge on their own (Hamm *et al.*, 2013).

The study by Ramnarain (2016) on the pedagogical approach of South African science teachers demonstrated intrinsic and extrinsic factors that prevent teachers from using inquiry-based instruction. Intrinsic factors include lack of professional science knowledge (content knowledge, pedagogical content knowledge, pedagogical knowledge, knowledge of students, educational contexts, curricular knowledge, and educational purposes), while extrinsic factors include school ethos, professional support, resource adequacy, and time that hinder teachers from using inquiry-based instruction.

1.3 Problem statement and rationale

For many years, teaching of first-year physics has been conducted in a traditional way. At UP lectures combined with problem-solving/tutorial sessions are carried out in large lecture halls. Practical laboratory work is also done to supplement the physics content taught during the lectures. This study aims to explore whether the Department of Physics' initiative of redesigning recipe-based physics laboratory practical activities into inquiry format has fruitful results. The increase in inquiry instruction is a recent trend in science education and has increased the need for further research into inquiry-based approaches.

Problem statement

Due to the increased use of inquiry-based approach in science instruction, it is necessary to determine the combination of guided inquiry (GI) laboratory practical activities and explicit-reflective questions (ERQs) on NOS understanding and to determine if GI laboratory practical activities and ERQs have an equivalent effect compared to traditional laboratory practical activities combined with ERQs on students' learning outcomes.

Rationale

Redesigning the laboratory component of a physics course from a traditional to an inquiry-based format offers an opportunity to explore the effects that guiding ERQs in GI has on the outcomes achieved in a first-year Bachelor of Science physics course. These include,

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specifically, the effect of the combination of GI and ERQs on students' understanding of NOS, performance in a combined practical examination, academic performance and students' attitudes towards the laboratory work. The rationale behind this transformation is that the current practice of doing the practical laboratory activities is procedural which, according to literature, does not enhance students' thinking skills (McDermott, 1991, 1993; Newton, Driver & Osborne, 1999). Additionally, McDermott (2006) asserted that one way of attaining more students' interest in science and science teaching is through transforming introductory physics courses.

The intervention is guided inquiry instead of procedural practical activities. McDermott's speciality is in physics education, therefore this reference is particularly relevant. The study on the pedagogical orientations of South African physical sciences teachers towards inquiry or direct instructional approaches by Ramnarain and Schuster (2014) found that overall teachers at township schools follow direct-teaching of science knowledge coupled with confirmatory practical work. Conversely, teachers at suburban schools use a guided inquiry instruction, and science knowledge developed through a guided exploration phase. The study further showed that the teaching methods used by teachers are influenced by contextual factors including class size, availability of resources, teacher competence and confidence, time constraints, student ability, school culture and parents' expectations.

The benefits of inquiry-based activities may be amplified by asking intellectually guiding questions which direct students' thinking and help a teacher to understand students' thinking (Clough, 2007). Clough (2007) also extended this argument to indicate that asking questions is an effective way to enhance students' understanding of epistemological beliefs and NOS. According to Clough and Olson (2008), NOS is knowledge that needs to be understood rather than to be known. Moreover, using guiding reflective questions in science instruction may facilitate the learning of scientific content (McGlathery, 1978; Redfield & Rousseau, 1981). Teachers should ask guiding reflective questions during inquiry-based activities which may elicit students' prior knowledge and deeply held misconceptions (Allchin, 2011; Clough, 2007). Additionally, guiding reflective questions may help a teacher to design activities that may also promote a deep and robust understanding of the desired science knowledge. Through questioning students may transform pre-existing misconceptions in their schemas into acceptable science knowledge.

1.3.1 Differences between traditional recipe-based and inquiry-based practical activities

The content-oriented curriculum and assessment methods guide science lecturers to pay attention to physics concepts, even in a laboratory-based practical course, rather than on the conception of NOS, acquisition of the scientific inquiry (SI) skills, development of scientific reasoning skills and positive attitudes towards science learning. Others argue that science should be learnt the way it is practised (e.g. Bybee, 2000; McDermott, 2006; McDermott, Heron, Shaffer & Stetzer, 2006; Schwab, 1962). Scientists, through scientific practice, gather data, analyse and interpret data, develop scientific knowledge by drawing conclusions and presenting their results. In this study, practical activities refer to students' hands-on experiments that are conducted in a physics laboratory. The two types of practical activities used in the current study are recipe-based and guided inquiry-based laboratory practical activities. The outcomes of these two types of practical activities will be compared. The differences between recipe-based and guided inquiry-based practical activities have been summarised in Table 1.1 below.

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Despite many research papers that show the benefits of inquiry-based laboratory approaches, traditional recipe-based experiments (also referred to as verification, traditional or expository labs) are used most of the time (Abraham, Cracolice, Graves, Aldamash, Kihega, Gill & Varghese, 1997). In traditional experiments, students usually work through structured procedures to attain a prearranged result. Accomplishment in this type of practical activities is decided by how well students' results resemble the established results.

Recipe-based practical work in many universities is often used to either 'confirm' or 'validate' a scientific principle or theory (Haigh, France & Forret, 2005). The expository experiments dominate the laboratory curriculum in many universities since they are easy to set up, easy to supervise, and to assess (Montes & Rockley, 2002). Activities associated with this type of experiment may be allocated into available periods. Laboratory assistants may be trained to control students' development as students' questions are foreseeable. Only a limited amount of conceptual understanding usually develops as a result of conducting expository experiments (Gallet, 1998; Gunstone & Champagne, 1990) and traditional experiments do not increase students' interest and motivation in further conducting scientific investigations (Montes *et al.*, 2002).

Research efforts have shown that the recipe-based practical activities are insufficient to enhance students' habits of mind because students are given step-by-step instructions to arrive at a pre-determined answer or knowledge (Banchi & Bell, 2008; Bell, Smetana & Binns, 2005; Cothran, Geiss & Rezba, 2000). There is little questioning and thinking involved while performing an activity. Even at the end of a practical activity after students would have found an answer that confirms a theory, they may find the whole investigation process uninteresting and discouraging. Subsequently, recipe-based practical activities do not promote the development of an inquiring mind-set. In this regard, inquiry-based practical activities may bring about changes in students' thinking and problem-solving skills.

It is claimed that inquiry-based instruction may enhance the development of scientific knowledge (NRC, 1996, 2000; Windschitl, 2008). There are two essential teaching strategies, namely case study and problem-based learning (Herried, 2007; Hmelo-Silver, 2004) which are believed to encourage students in critical thinking and problem solving. These two approaches engage students in active learning and enhance students' epistemological beliefs and understanding of the nature of science (Cliff & Nesbitt, 2005; Conley, Pintrich, Vekiri & Harrison, 2004; Herried, 2007; Hmelo-Silver, 2004; Lunberg, Levin & Harrington, 1999; Sahin, 2010). Epistemological beliefs are individual ideas involving the nature of knowledge and how knowledge is constructed (Hofer & Pintrich, 1997; Nussbaum, Sinatra & Poliquin, 2008). When students are provided with problems in case studies or in investigative tasks, they may be engaged in the practices of scientific inquiry such as the formulation of questions, forming hypotheses, planning investigations, collection of data, analysing and understanding data, formulating conclusions, justifying conclusions with evidence and presentation of the results (Allchin, 2001b; Conley *et al.*, 2004; Herried, 2007; Hmelo-Silver, 2004; Sahin, 2010).

Gil-Perez, Guisasola, Moreno, Cachapuz, Pessoa De Carvalho, Martinez Torregrosa, Salinas, Valdes, Gonzalez, Gene Duch, Dumas-Carre, Tricarico, and Gallegos (2002, p.560) describe what they regard as proper students' responsibilities in science learning:

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Table 1.1 Guided inquiry and traditional recipe-based laboratory practical activities (Adapted from Wenning, C.J. (2005a). Levels of inquiry: Hierarchies of pedagogical practices and inquiry processes. *Journal of Physics Teacher Education Online*, *2*(3), 3-11).

Traditional recipe-based practical activities	Guided inquiry-based practical activities
Students follow step-by-step instructions without thinking about them, promoting recipe-following behaviour.	Students are given questions to engage with that lead them through the practical activity.
Students' activities involve confirming knowledge learnt in class encouraging a shift from abstract to concrete.	Students' activities involve gathering data, interpreting data and formulating conclusions, encouraging students to shift from the concrete to the abstract.
Students are given experimental designs that instruct them which variables to hold constant, which to vary, which are the independent and dependent variables, respectively. It is assumed that students will implicitly acquire scientific inquiry skills by performing experiments.	Expect students to generate their own experimental designs. Students are encouraged to independently identify, distinguish, and control appropriate independent and dependent variables; thus promoting students' acquisition of the scientific inquiry skills
Students are rarely given opportunities to learn from their mistakes.	Generally provides students with opportunities to recover and learn from their mistakes.
Use procedures that are contradictory to the scientific practice; demonstrate procedural linear process.	Use procedures that are in agreement with the real scientific practice; illustrate the work of science to be recursive and self-correcting.

> *"…It is difficult to oppose the view that pupils by themselves cannot construct all scientific knowledge… A metaphor that contemplates pupils as novice researchers gives a better appraisal of the learning situations. Effectively, every researcher knows that when someone joins a research team, he or she can catch up quite easily with the standard level of the team. And that does not happen by verbal transmission, but through the treatment of problems in fields where his or her more experienced colleagues are experts".*

Millar (2004, p.3) emphasises the importance of placing learners in the centre of scientific inquiry:

> *"Encouraging students to pursue their own enquiries taps into their natural curiosity. Finding things out for yourself, through your own efforts, seems natural and developmental, rather than coercive, and may also help you to remember them better. It seems to offer a way of holding up evidence, rather than authority, as the grounds for accepting knowledge. It is enabling, rather than dismissive, of the individual's ability, and right, to pursue knowledge and understanding for her/himself. Indeed one of the great cultural claims of science is its potential as a liberating force – that the individual can and may, though his or her own interaction with the natural world, challenge established tradition or prejudice, by confronting it with evidence. An enquiry-based approach may also encourage students to be more independent and self-reliant. In this way it supports general educational goals such as the development of individuals' capacity for purposeful, autonomous action in the world".*

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An examination of the works of John Dewey and Joseph Schwab is foundational to the understanding of inquiry. In the twentieth century science was taught as a fixed body of knowledge but not aimed at transforming students' thinking and attitudes. Dewey (1964, p.183) argued that "Science has been taught too much as an accumulation of ready-made material with which students are to be made familiar, not enough as a method of thinking, an attitude of mind, after the pattern of which mental habits are to be transformed." Dewey's (1933) view of inquiry- and problem-based learning strategies encourage the constructivist's view of learning in a classroom setting. Elements of both inquiry- and problem-based learning engage students in formulating problem statements or hypotheses, gathering of data to address their established problem, formulating conclusions as well as reflecting on them (Woolfolk, 2007). Joseph Schwab suggested a perspective of inquiry in 1965 which was closely related to the work of real scientists (Wallace & Kang, 2004). In other words, inquiry-based science instruction involves students in different phases of engagement in investigation, evaluation and presentation of the findings (Sandoval, 2005).

The use of inquiry-based instruction provides students in high schools and universities with an opportunity to acquire problem-solving and reasoning skills by conducting hands-on science activities (Scruggs & Mastropieri, 1993). Dewey (1964, p.188) speaks of knowledge that:

> *"Never can be learned by itself, it is not information, but a mode of intelligent practice, a habitual disposition of mind. Only by taking a hand in the making of knowledge, by transferring guess and opinion into the belief authorized by inquiry, does one ever get knowledge of the method of knowing. Because participation in the making of knowledge has been scant, because reliance on the efficacy of acquaintance with certain kinds of facts has been current, science has not accomplished in education what was predicted for it."*

Doing an experiment in which they go through the scientific process may improve both students' conceptualisation of epistemological beliefs as well as their views on NOS. For instance, Conley *et al.,* (2004) investigated the effect of inquiry-based instruction and hands-on activities with fifth grade elementary students over nine weeks and found that they developed more sophisticated epistemological beliefs when pre- and post-tests scores of the study were compared. The results demonstrated that the case study and the Problem-Based Learning (PBL) approaches that integrate real empirical data and contexts are likely to enhance college students' epistemological beliefs and understanding of NOS.

On a broad scale, empirical research studies demonstrate that inquiry-based instruction may also enhance a reflective learning style in students (Elton, 2001; Zwickl, Finkelstein & Lewandowski, 2013). This may enable students to have a better understanding of physics concepts, and promote better academic performance in physics courses (McDermott, 1996; McDermott, Shaffer & Constantinou, 2000). Students that view science content as a fixed body of information that can be discovered experimentally, usually resort to rote ways of learning science (Wallace, Tsoi, Calkin & Darley, 2003). Conversely, students with constructivist perspectives tend to view science as an imaginative and creative human endeavour. Students may develop an understanding of scientific inquiry and the importance of finding "the path of experiment and induction by which science develops" (Dewey, 1964, p. 189).

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The benefits of involvement of students in GI laboratory activities may be explained in terms of self-determination theory (Deci, 1975; Deci & Ryan, 1987). This theory posits that students have needs such as proficiency, independence and connection, which require the attention of teachers. When these needs are addressed, students become internally motivated and their learning may be enhanced. A GI-based learning environment provides students with more autonomy in their learning process. When students are asked guiding intellectual engaging questions, when they are actively involved in the design of the investigation, and when they can collaboratively work together and interact with their colleagues and laboratory assistants in gathering data, and in analysing and interpreting the data, they may develop sense of ownership of their learning process and the investigation process may become enjoyable to them.

The inquiry laboratory practical activities are believed to promote constructive relationships amongst students, enhance positive attitudes and cognitive development (Hofstein & Lunetta, 1982; Lazarowitz & Tamir, 1994; Lunetta, 1998). In their critical analysis of the school science laboratory, Hofstein and Lunetta (2003) further argued that inquiry-based laboratory experiences do not only help students to understand ideas, frameworks of ideas and communication skills, but also help students acquire ideas about the nature of a scientific community, NOS and appreciation of the construction of scientific claims. To achieve these goals according to Hofstein *et al.* (2003) students should be given investigative tasks and afforded opportunities to reflect on them.

McBride, Bhatti, Hannan and Feinberg (2004) asserted that teaching students the process of science as inquiry is better than teaching students factual knowledge. Procedural knowledge involves learning the process of inquiry but declarative knowledge is about learning factual knowledge (Bitan-Friedlander, Dreyfus, & Milgrom, 2004). On the other hand, Kruckeberg, (2006) argues that declarative knowledge is learnt through the use of procedural knowledge. Put differently, if students learn the scientific inquiry skills, these skills may support learning of the factual information. Using inquiry-based instruction students may learn less factual information but with a deeper understanding (McBride *et al.*, 2004; NRC, 2000).

The AAAS (1993, p. 320) articulated the slogan "less is more" which guides the curriculum development and science instruction in agreement with the reform documents. The NRC (2000) indicates that there should be a paradigm shift in science education from covering a large scope of subject content at surface level to a deep understanding of fewer concepts. Put differently, students may develop a better understanding if they study fewer topics in depth rather than studying many topics at a superficial level as it is done in many South African schools. Carefully thought out inquiry-based laboratory practical activities may give students opportunities to develop a deeper understanding of science concepts, develop conceptions of NOS and scientific inquiry skills. These learning outcomes may be attained if the teaching and learning environment provides teachers with time for students to participate and reflect in inquiry-based activities. On the other hand, learning outcomes should be understood as multifaceted. The goals of learning should go beyond the development of conceptual and procedural knowledge to the development of creative and critical thinking skills in science which may train students to become persistent learners and adaptive specialists (Bereiter & Scardamalia, 2006; Bransford, Brown & Cocking, 2000; Sandoval & Reiser, 2004).

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1.3.2 Barriers to implementation of inquiry and NOS instruction

Some researchers disagree that Inquiry-based Science Education (IBSE) may promote the development of scientific knowledge in learners. For instance, Smith and Anderson (1999) argue that each method of instruction has its advantages as well as disadvantages. Brown, Abell, Demir and Schmidt, (2006) posit that IBSE has its own drawbacks. Firstly, some students may require more structure than that provided by inquiry-based teaching. Secondly, inquiry instruction is not an effective method of disseminating a large quantity of information to many students within a short period. Many teachers have problems in managing a class of students engaged in inquiry-based activities (Welch, Klopfer, Aikenhead & Robinson, 1981). In other words, teachers do not have as much control over the learning process since the classroom is student centred. Moreover, the majority of teachers feel ill-prepared to implement inquiry instruction because they did not learn science and mathematics through an inquiry approach themselves (NRC, 2000; Weiss, Pasley, Smith, Banilower & Heck, 2003).

The majority of teachers tend to view the inquiry approach as an ineffective teaching strategy in their classes since it is difficult to implement and because of the length of class time involved in completing a lesson or conveying a concept (Brown *et al.*, 2006; Dancy & Henderson, 2010; Felder & Brent, 1996; Lotter, 2004; Zion, Cohen, & Amir, 2007). For instance, when students are engaged in investigation or a discourse the teacher may wish to allow students to proceed with their work but the time factor may be a challenge as teachers are pressurised to cover all curriculum content before the end of the year final examination (Jasperson, 2013).

In addition, many teachers avoid using inquiry instruction because this approach often causes students to become confused and frustrated in learning (Bodner, Hunter & Lamba, 1998; Domin, 1999a). Felder *et al.* (1996) contended that teachers may for example encounter initial awkwardness and student hostility when implementing an inquiry approach for the first time. Reif (2008) argued that students who perform well in conventional methods are likely to object to the inquiry-based instruction. Reif further suggested that students feel threatened and exposed if they have to present their ideas in front of the whole class. Inquiry-based teaching involves extracting students' ideas and addressing students' alternative views/misconceptions. This may cause a cognitive conflict amongst the students (Felder *et al.*, 1996).

Cognitive conflict teaching approach may frustrate students because they lack the necessary mental tools to alleviate dissonance (Kirschner, Sweller & Clark, 2006). Kirschner *et al.* (2006) also observe that students learning science in classrooms through pure discovery methods experience frustration and confusion which may result in the development of misconceptions, since they are not guided in the learning process. Brown and Melear (2006, p.954) propose that when teachers acquire science knowledge via an open-inquiry process, they "often experience a loss of confidence in their science knowledge". Tobin and McRobbie (1996) posit that there are cultural beliefs that pressurise teachers to use teacher entered approaches in contrast with teaching science knowledge as inquiry (Lotter, Harwood, & Bonner, 2007).

Moreover, the variation in meanings for inquiry instruction generates challenges for both science education researchers and teachers. On one hand the National Science Education Standards, NSES (e.g. AAAS, 1993; NRC, 1996) recommend the teaching of scientific

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inquiry in all grades. On the other hand, the NGSS encourages learning goals that incorporate science practices, cross-cutting ideas, and core ideas (NGSS Consortium of Lead States, 2013). Furthermore, there are different levels of inquiry which could be confusing and overwhelming for teachers, thus hindering the use of inquiry in science instruction (Van Hook, Huziak-Clark, Nurnberger-Haag & Ballone-Duran, 2009; Wee, Shepardson, Fast & Harbor, 2007).

Other scholars (e.g. Blanchard, Annetta, & Southerland, 2008; Marzano, 1998) have claimed that standardised testing has discouraged teachers from implementing inquiry in three different ways. Firstly, it has reinforced teaching practices that differ from those encouraged in the national science education reform documents (AAAS, 1993, 2000; Crawford, 2007; Gallagher, 1989; Lederman, 2004; McGinnis, Parker, & Graeber, 2004; NRC, 1996, 2000; Roehrig & Luft, 2004; Welch, Klopfer & Aikenhead, 1981). Secondly, it has strengthened science teachers' negative perception of their teaching practice (Shaver, Cuevas, Lee, & Avalos, 2007; Southerland, Abrams & Hutner, 2007). Thirdly, it has generated pressure for teachers to train their students for the tests that include an extensive amount of content (Whitford & Jones, 2000). Additional barriers described in the literature that hinder the implementation of inquiry include absence of administrative support (Zion, Cohen & Amir, 2007) and contradictions of personal experiences and ideas in scientific inquiry (Trumbull, Scarano & Bonney, 2006; Crawford, 1999, 2007). Subsequently, teachers resort to a traditional approach of teaching factual knowledge for students to succeed in standardised proficiency tests. Nonetheless, teachers should be supported in using inquiry rather than a teacher-centred approach and in curbing the political as well as cultural pressure imposed by parents and administrators (Anderson, 2002; Anderson, 2007).

Since the understanding of NOS is believed to be promoted by the IBSE approach (AAAS, 1993; NRC, 1996), some of the barriers documented in the literature regarding NOS instruction (Bell, Lederman & Abd-El-Khalick, 2000; Lederman, Schwartz, Abd-El-Khalick & Bell, 2001) need to be discussed. They include:

- Teaching of NOS is time intensive and teachers spend most of their time addressing traditional science content (Abd-El-Khalick *et al.*, 1998; Drayton & Falk, 2001; Olson & Clough 2001; McBride *et al.*, 2004).
- Pressure on teachers to complete content (Duschl & Wright, 1989; Hodson, 1993),
- NOS instruction is perceived as unimportant compared to other cognitive outcomes like teaching science content and processes (Abd-El-Khalick *et al.,* 1998).
- Teachers' misconceptions of NOS and science processes, absence of knowledge associated with instructional approaches for NOS (Abd-El-Khalick, 1998).
- Absence of subject matter content knowledge (Schwartz & Lederman, 2002), that impedes explicit and reflective teaching of NOS.

Irrespective of the aforementioned drawbacks of inquiry, the study should establish if inquiry does or does not have an effect.

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1.4 Significance of the study

Learning through inquiry provides a less content-oriented, metacognitive, collaborative, argumentative and communicative learning environment (Berge & Slotta, 2005). In addition, inquiry instruction may empower students to become independent lifelong learners and provides students with an opportunity to develop an appreciation of discovery (Llewellyn, 2002). Inquiry may also enable students to create their own knowledge by establishing connections between their pre-existing knowledge and new experiences (Berge *et al.*, 2005; Tobin; Tippins, & Gallard, 1993). Inquiry-based approaches engage students in cognitive processes used by scientists such as asking questions, formulating hypotheses, planning investigations, collecting and interpreting data, drawing conclusions and formulating theories (Crawford, 2000). Performing these activities encourages students to create a broader conception of science and enhances their critical reasoning and problem solving skills (Bodzin, 2005; Scruggs *et al.*, 1993). Moreover, inquiry may also contribute to the development of science content understanding, and provide students an opportunity to use their scientific understanding in addressing research questions by discovering new scientific principles, transforming their prior knowledge and encouraging them to seek more knowledge (Edelson, Gordin & Pea, 1999).

Past studies have shown that there is a weak understanding of introductory physics by students taught through the traditional approach (Kalman, 2002; Kubli, 2001; Stinner, 2006). Thus, the researcher proposes that the use of explicit reflective guiding questions combined with GI-based practical activities may improve the learning and attitudes towards physics. This study has explored the degree to which guiding reflective questions together with GI-based laboratory activities, as suggested by Clough (2007), influence the students' outcomes. The NRC (1996, p. 105) posited that

> *"Students at all grade levels and in every domain of science should have the opportunity to use scientific inquiry and develop the ability to think and act in ways associated with inquiry, including asking questions, planning and conducting investigations, using appropriate tools and techniques to gather data, thinking critically and logically about relationships between evidence and explanations, constructing and analysing alternative explanations, and communicating scientific arguments".*

It is anticipated that the results of this study may enhance the understanding of current science laboratory practices and the potential effects of inquiry-based instruction at university level. The current study intended to investigate the following learning outcomes: students' understanding of NOS, students' performance in the combined practical examination as well as students' academic performance and attitudes towards the laboratory work. 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 research may also be beneficial not only to physics lecturers and students but also to curriculum developers, educational authorities and in general to the education system. Physics lecturers may engage their students in investigations in a safe learning environment. Students may become proficient in the epistemology of science knowledge, framing and seeking resolutions associated with inquiry activities and real-life problems.

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1.5 Aims and research questions

1.5.1 Aims

Acting on Clough's (2007) thinking, this study aims to explore whether changing some of the traditional laboratory activities into GI format integrated with ERQs that support the discovery of specific aspects of NOS, may influence the outcomes of the first-year physics course. As such, the other aim of this study was to obtain both qualitative and quantitative data on the experiences of students while engaged in GI practical activities and after the NOS course. This data may provide a window into the development of students' conceptions of NOS. Moreover, the data may shed some light on the effectiveness of ERGI laboratory practical activities in the development of students' views on NOS, attitudes towards science learning and academic performance.

1.5.2 Research questions

This study will address the following main research question:

> *To what extent does explicitly reflective guided inquiry-based instruction in practical laboratory activities influence the outcomes achieved in a first-year physics course?*

The question is addressed through four sub-questions, namely:

To what extent do guided inquiry-based laboratory activities and ERQs promote:

- *Understanding of the nature of science,*
- *Attitudes towards laboratory work,*
- *Conceptual development,*
- *Academic performance?*

1.6 Assumptions for redesigning traditional physics laboratory practical activities into guided inquiry-based format

The current study drew on the theoretical concepts founded in the literature of inquiry-based learning. This study shares the same constructivist perspectives as Redish (1997) regarding the teaching of physics. Students should be guided to realise what physics is, how physics works and how it relates to people's lives. Inquiry-based instruction has four constructivist elements within it that encourage learning (Driscoll, 2005; Slavin, 2006). Firstly, emphasis is on the development of knowledge by an individual learner. In the learning process, a learner is provided with opportunities to blend new experiences with existing prior knowledge (Blumefeld, 1992; von Glasersfeld, 1995). Secondly, according to the constructivist view, learners may learn effectively from negotiated meanings through social interaction with fellow learners (Savery & Duffy, 2001; Scadamalia & Bereiter, 1991; Vygotsky, 1978). The constructivist perspectives encourage the discussion of different views regarding subject matter between and within groups of students of similar understanding that also collaboratively work together. Additionally, discussions amongst students may be used as a

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measure of their prior knowledge (Slavin, 2006). Thirdly, establishing a goal, planning and controlling an individual's self-regulated learning are critical features of constructivist views of learning. Lastly, constructivist approaches to learning utilise meaningful tasks during teaching to relate subject matter learnt in class to real-life situations (Loyens, Rikers & Schmidt, 2007).

Tobin (1990, p. 405) declared that "constructivism implies that students require opportunities to experience what they are to learn in a direct way and time to think and make sense of what they are learning". Students should be assisted to develop an understanding of what they do in scientific investigation, why they should conduct investigations, how they should conduct investigations as well as how to synthesise explanations of their experiences instead of receiving ready-made knowledge from the teacher. In short, constructivism integrates and uses students' interests, prior knowledge, and new experiences as a foundation upon which learning may occur. According to Dewey (1938, p. 25) inquiry is described as "an organic connection between education and personal experience".

The use of inquiry has been conducted in different science disciplines including physics, chemistry and biology. In inquiry-based instruction, teachers are provided with an opportunity to facilitate students' experiences in the discovery of knowledge. Thus, inquiry enhances students' learning (Apedoe, 2008; Arends, 1997; Asay & Orgill, 2010; Gott & Duggan, 1995; Lloyd & Contreras, 1985). Moreover, inquiry enhances students' critical thinking (Narode, Heiman, Lochhead & Slomianko, 1987), and construction of logico-mathematical knowledge (Staver, 1986).

The integration of the context with the concept to be learnt may promote the development of scientific inquiry skills (Hofstein, Shore & Kipnis, 2004; Kipnis & Hofstein, 2008). Tobin (1990) asserts that effective learning may occur in the laboratory if students could be allowed to select the apparatus and resources required for the construction of knowledge of a phenomenon. Sriwattanarothai, Jittam, Ruenwongsa and Panijpan (2009) found that after engaging undergraduate students in the inquiry-based laboratory, they developed a better conceptual understanding of the studied issues. The experimental work was carried out before the lecture and enhanced understanding of the science concepts. Hofstein *et al.*, (2004) also established that students' ability to ask better scientific questions improved after participating in inquiry-based experiments.

In addition, the current study assumes that students' learning goals (Greene & Miller, 1996), intrinsic motivation (Pintrich & Schunk, 1996), self-efficacy (Zimmerman, Bandura, & Martinez-Pons, 1992), cognitive strategies and self-regulated learning may increase while conducting GI laboratory practical activities which may also contribute to high academic performance (Bandura, 1986 & 1991). Constructs such as students' learning goals, motivation and self-efficacy will again be addressed in detail later in this study.

For teachers to help students to become 21st century thinkers, students should not only understand the basic science concepts, but they should acquire problem-solving skills and critical thinking skills through inquiry instruction (Jasperson, 2013; Millar, 2006). Jasperson further argued that science teachers in the US should not only be mindful of the common national core standards but they must develop an insight into the theoretical framework for the New Science Education Standards (NGSS Consortium of Lead States, 2013). One hindrance in implementing inquiry is that there is a common belief among teachers that inquiry may be used as a tool of teaching process skills but not content (Jasperson, 2013).

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This has led teachers to rely upon cookbook laboratory, worksheets and teacher-centred activities in teaching basic science content. In addition, teachers have had little or no training on using inquiry-based teaching and have abandoned the idea. Reducing learning to simple memorisation of a fixed body of facts deprives students of an opportunity to become independent problem solvers (Jasperson, 2013). In this study, the researcher advocates the view that GI trains students to be lifelong learners by employing strategies that enhance effective learning of science knowledge.

1.7 Benefits of using guided inquiry

In the intervention, GI was used because of various reasons. Firstly, GI integrates the instructional advantages of open-inquiry approaches with the practical advantages of recipe-based experiments. In GI practical activities (also referred to as discovery-based activities) students are provided with the question and apparatus, but not the method to reach a predetermined but undeclared outcome. Secondly, allowing students to participate in GI may enhance their cognitive development more than performing traditional practical activities (Domin, 1999; Pickering, 1988; Tobin *et al.*, 1993). Learning through inquiry provides a less content-oriented, metacognitive, collaborative, argumentative and communicative learning environment (Berge *et al.*, 2005). Learning through inquiry may empower students to become independent lifelong learners and provides students with an opportunity to develop an appreciation of discovery (Llewellyn, 2002). It also enables students to create their own knowledge by forming connections between their pre-existing knowledge and new experiences (Berge *et al.*, 2005).

In contrast to open-inquiry, GI may be readily adapted to large laboratory sessions. Additionally, GI-based laboratory practical activities maximise group discussion and argumentation in the scientific inquiry. Learning of physics concepts may be improved if group discussions between students are encouraged (Watson *et al.*, 2004). Inquiry-based approaches involve students in cognitive processes used by scientists such as asking questions, formulating hypotheses, planning investigations, collecting and interpreting data, drawing conclusions and formulating theories (Crawford, 2000; Edelson, Gordin & Pea, 1999). Performing these activities may afford students opportunities to acquire a broader understanding of science and enhance their problem solving and critical reasoning skills (Bodzin, 2005). The National Science Education Standards (NRC, 1996) highlighted the contributions of inquiry-based instruction to teaching and understanding science. According to NRC (1996, p.2),

> *"When engaging in inquiry, students describe objects and events, ask questions, construct explanations, test those explanations against current scientific knowledge, and communicate their ideas to others. They identify their assumptions, use critical and logical thinking, and consider alternative explanations. In this way, students actively develop their understanding of science by combining scientific knowledge with reasoning and thinking skills".*

Moreover, inquiry may also promote the improvement of conceptual understanding of science content. Students may use their acquired scientific understanding in addressing research questions. In the process of resolving a problem, students may encounter scientific principles that could possibly transform their prior knowledge and encourage them to seek more knowledge (Edelson *et al.*, 1999).

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Furthermore, students' involvement in guided-inquiry experiments may increase their interest and motivation in learning science. In GI, students should be provided with Socratic guidance which may encourage them to think and develop some insights about a phenomenon under investigation (Arons, 1993). Socratic guidance depends on various factors such as the context in which it is applied, the vocabulary used by the teacher and the text, the way concepts have been developed and presented, the nature of guiding questions used, and the students' prior knowledge. Inquiry-based instruction is believed to promote the development of students' effective learning, conceptual development, NOS understanding (Apedoe, 2008; Asay *et al.*, 2010; Gott *et al.*, 1995; Sherman & Sherman, 2004) and acquisition of skills to become independent inquirers (Hofstein *et al.*, 2004; Kipnis *et al.*, 2008). Inquiry-based learning environments provide students with an opportunity to develop and refine their thinking in interdisciplinary contexts (Myers & Botti, 1997). The recent review of literature by the NRC (2000) posits that when students are explicitly taught on how to conduct inquiry activities, their cognitive skills, vocabulary knowledge, critical thinking, and attitudes toward science may be enhanced.

1.8 The design of the intervention

The first step towards ensuring effective change from recipe-based to GI-based laboratory practical activities at the Department of Physics within the Faculty of Natural and Agricultural sciences at the University of Pretoria (UP) was to outline the goals and objectives of the intervention. This was followed by outlining an assessment method of evaluating whether intended goals and objectives would be accomplished. At the beginning of the semester, the researcher and supervisors designed a plan of what we would like first-year physics students to learn from their inquiry-based laboratory practical activities. The intended learning objectives and skills were specifically worded to align with the aims of the Introductory Physics Laboratory of the American Association of Physics Teachers (AAPT) (1998). This study was aligned with the goals of the Introductory Physics Laboratory of the American Association of Physics Teachers (AAPT) (Feynman, 1998) (see Table 1.2). A detailed explanation appears in the original American Journal of Physics (Feynman, 1998).

The experimental group performed GI-based laboratory practical activities. Prior to implementation, the researcher and study leaders met several times to discuss theoretical perspectives and to develop a framework for implementation of the inquiry-based practical activities. The inquiry-based practical activities were designed using McDermott's (1996) Physics by Inquiry (PbI) model and the Physics and Everyday Thinking (PET) curriculum by Goldberg, Otero and Robison (2010) with the aim of making the activities enjoyable and allowing students to explore learning trajectories that arose from the instructional context.

These inquiry-based activities were set up according to the recommendations of Clough (2007) and were aimed at improving problem-solving skills, designing skills, creative and critical thinking skills and decision-making skills which are believed to be advanced by inquiry-based instruction.

The control group performed the laboratory activities in the traditional recipe-based way. The instructions were taken from the existing practical manual but adapted so that both the inquiry-based and the traditional practical activities covered essentially the same work and had the same format and writing style.

The class used calculus-based physics textbook entitled the Principles of Physics (9th Ed) (Halliday, Resnick & Walker, 2010). The experimental work mainly addressed some

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Table 1.2 Summary of the goals of ERGI laboratory practical activities as adapted from Feynman, R. (1998). Goals of the Introductory Physics Laboratory: American Association of Physics Teachers. *American Journal of Physics*, 66(6), 483-485.

I. **The Art of Experimentation:** The ERGI laboratory should involve individual students in acquiring experiences with experimental processes and designing scientific investigations.
II. **Experimental and Analytical Skills:** The ERGI laboratory should assist students to acquire a variety of experimental physics basic skills such as collecting data, plotting graphs, analysing and interpreting data and drawing conclusions.
III. **Conceptual Learning:** The ERGI laboratory should assist students to develop an understanding of physics concepts.
IV. **Understanding the Basis of Knowledge in Physics:** The ERGI laboratory should assist students to understand the influence of observation in physics and to differentiate between conclusions derived from a theory and those from laboratory practical activities.
V. **Developing Collaborative Learning Skills:** The ERGI laboratory should assist students to acquire collaborative learning skills that are essential in real-life contexts.

scientific theories, principles and laws related to the electricity and magnetism topics taught in the theory section of the course.

The study was conducted during the second semester of 2014 with the first-year calculus based Bachelor of Science physics course. The laboratory component of the course comprised of eight, two-hour long practical sessions. During the laboratory sessions students functioned in small groups of two or three. The list of practical activities included: simple harmonic motion (SHM), exponential decay (EKS), DC circuits (CIR), discharging a capacitor (RC), oscilloscope (OSS), alternating current (AC), transformer (TRA) and the current balance (CUR). Unlike lecture and problem-solving sessions, each laboratory session lasts for two hours and was compulsory. The practical course was assessed at the end of the laboratory sessions through a combined practical examination comprising of both a written and a hands-on practical examination.

Prior to the commencement of eight practical sessions, students were given one practical activity on the use of a multi-meter. This first practical activity focused on teaching students the skills on how to measure current, resistance and voltage using a multi-meter and on the drawing of graphs. This activity was conducted by both experimental and control groups of students. For the remaining 8 sessions, the laboratory groups followed a weekly rotation schedule to ensure that all laboratory activities were completed by all groups. Laboratory assistants were assigned to a specific experiment and did not rotate with the groups.

1.8.1 The practical course

The practical course was based on the existing recipe-based practical course. For the control group, the recipe-based structure was retained. Care was taken to ensure that, except for the pedagogical approach, the practical activities for the control and experimental groups were as far as possible, identical.

The practical activities done by the experimental group involved ERGI laboratory practical activities informed by the generalisations about teaching and learning that resulted from the development of PbI and Tutorials in Introductory Physics (McDermott, 2001). Physics by Inquiry (PbI) and Tutorials in Introductory Physics are the two curricula that have been developed and published by McDermott and Physics Education Research Group (1996) and McDermott and Shaffer (2002). These curricula have been developed through extensive

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research, curriculum development and teaching. In both curricula students are actively involved in the process of learning physics. Science teaching, in both curricula, is elicited by questioning rather than telling. The purpose of questioning encourages the development of thinking and reasoning skills in students.

PbI is a classroom-tested inquiry-based laboratory curriculum developed as a university course that consists of carefully structured experiments, exercises and questions that promote active intellectual involvement. This curriculum was developed to prepare elementary and secondary school science teachers to teach physics and physical science effectively (McDermott, 2006, 1990, 1975, 1974; McDermott *et al.*, 2006). In addition, PbI also enhanced teachers' competence and confidence in science instruction. The Tutorials in Introductory Physics is a supplementary curriculum composed of tutorials that are intended to be used with university students during study in addressing introductory physics content.

The PbI curriculum creates opportunities for teachers to learn science the way it should be taught in class. This curriculum has also been used with high school and university students. In the PbI modules students should always be encouraged to work collaboratively in small groups (McDermott *et al.*, 2000). The PbI is characterised by four broad principles which include:

- Concepts, reasoning ability and representational skills are integrated with the subject matter to be learnt by students,
- Physics is taught as a process of inquiry rather than as a fixed body of information,
- Science instruction should encourage students to establish the link between the formalism of physics and real world phenomena.
- PbI consists of a set of modules which address certain common conceptual and reasoning difficulties that are experienced by students in physics learning.

Moreover, the PbI curriculum promotes effective involvement of students in the learning process. 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. In all the PbI modules, students should, in small groups, demonstrate an ability to conduct scientific investigations, observe and collect data, be guided into translating data into evidence, assisted in linking their evidence to existing scientific theories and to construct physics concepts through analytical reasoning skills. Put differently, the development of physics concepts starts with observations made by students, formulation of reasonable expectations, and guidance through a chain of reasoning that may enable students to develop conceptual model of a phenomenon under investigation. In addition, students should have acquired skills to translate developed physics concepts to predict and explain the behaviour of similar physical phenomena.

In this study the questioning strategy HRASE (History, Relationships, Application, Speculation and Explanation) as proposed by Penick, Crow, and Bonnstetter (1996) was used. The HRASE strategy uses students' prior knowledge as a breeding ground for building relationships between ideas, applying knowledge in new situations and creation of explanations. In all stages of the investigation process intellectual engaging questions, that required qualitative reasoning and verbal explanations were used to enhance students' learning. Firstly, guiding questions were used to assist students in designing their different

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investigation procedures of solving the problems presented to them. Secondly, guiding questions directed students in collecting data, representing their data using diagrams and graphs, interpreting their graphs and drawing conclusions from the graphs. Thirdly, guiding questions were employed to probe students' thinking in depth and to inspire students to shift from a lower level of reasoning to a higher level where they could synthesise a conceptual model from the gathered data.

According to the revised Bloom's taxonomy of educational objectives teachers should ask high order thinking questions which may assist students to progress from lower levels to higher levels of thinking (i.e. recalling, comprehension, application, evaluation and generation) (Anderson & Krathwohl, 2001). For instance, high order intellectual questions should start with the words such as "how", "why", "what" rather than "can", "will", "did" (Clough, 2007). Additionally, during the investigation process laboratory assistants used Socratic dialogue to guide and provide necessary scaffolding for students to develop conceptual models of concepts and phenomena being investigated. In so doing, students were actively involved in the construction of knowledge as suggested by the constructivist perspective of learning.

Empirical research demonstrates that the inquiry-based practical activities usually take a longer period than recipe-based ones (Maley *et al.*, 2013). In this current study, however, the GI and traditional laboratory practical activities were designed in a way that allowed students sufficient time to complete the activities. Put differently, the experimental and control groups of students had equal contact time for performing their practical activities. Furthermore, aspects of the practical activities were included as "optional", allowing these to be included or left out by the technical assistant on an ad-hoc basis.

The NOS aspects were addressed by questions that used the experiment as context. The aspects covered were: the tentative nature, empirical nature, difference between human observation and inferences, difference between a scientific theory and law, the influence of imagination and creativity, the influence of social and cultural aspects on the generation of scientific knowledge and misconceptions regarding the use of one scientific method (Khishfe & Lederman, 2006). Where applicable, historical scientific events were used as contexts to deepen students' NOS views (Abd-El-khalick & Lederman, 2000). Historical scientific events enable students to develop an insight on the epistemological beliefs surrounding the development of scientific knowledge. According to Allchin (2004), when students are provided with the historical case studies of error, they may learn about the development and limitations of science. The use of historical case studies may enable students to realise the way science works by exploring historical events where scientists succeeded or failed together with a discussion by a scientist. "Teaching science without error …is like teaching medicine without disease or law without crime. The result is disconnected from real practice" (Allchin, 2004b, p. 944).

As recommended by Clough (2007), the aspects of NOS were not explicitly taught to students however they were explored by adding one or two ERQs to be answered after the practical activity for both the control and the experimental groups, respectively, which were also evaluated. These questions were identical in both the recipe-based and ERGI laboratory practical activities. The use of explicit reflective instruction combined with GI and traditional recipe-based physics laboratory practical activities is utilised in the intervention course. When students are performing their laboratory practical activities, their attention may be directed to the investigative processes that are related to NOS aspects, and being asked to

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reflect on how their practical activities resemble or differ from the scientists' experiments (Schwartz *et al.*, 2002; Schwartz *et al.*, 2004).

Explicit reflective guiding questions on NOS were included in the intervention course because it was suggested by Nathan (2012) that students may develop a deeper understanding of abstract concepts if they work with concrete phenomena rather than being taught about abstract ideas.

According to Nathan (2012), if students are afforded an opportunity to have a deep reflection on evidence, they may notice data patterns which also require explanation. Subsequently students may realise that an explanatory model needs to have certain characteristics to explain the gathered data. This may further promote a better understanding of science content and NOS views.

The guided PbI model was implemented and it used the five designing principles similar to those in PET curriculum (Goldberg *et al.,* 2010). The principles included that: learning should build up on pre-existing knowledge, learning is a difficult activity that requires support. Learning is assisted by conducting scientific investigations using equipment in the physics laboratory, through social interactions of students and by establishment of certain behavioural practices as well as expectations. Each principle of the PET is further composed of four sub-categories, namely "purpose", "initial ideas", "collecting and interpreting evidence" and "summarizing questions".

The students in both groups were provided with preparation sheets. The purpose and initial ideas were mainly addressed by background information sheets describing the intended aims and skills to be developed for each activity. The background material also included the learning objectives and a brief outline of relevant physics information for each practical activity and referred students to the relevant theory sections of the textbook. Students were also provided with links to websites where they could find additional information on physics topics related to the practical activities. These sheets were identical for both groups and were available for download from the course website. To encourage students to read through the preparatory material, a short 10 minute test was written at the start of each session. Both experimental and control groups wrote the same pre-test. The pre-test counted 30% of the official practical mark for the experiment.

The equipment used by the two groups was identical, as were the practical activities, with the difference being that the control group had recipe-based instructions while the experimental group had inquiry-based instructions. To limit cross-contamination, students were handed fill-in practical worksheets at the beginning of each practical session, which would have to be submitted for marking at the end of the session. For the duration of the study, students were not allowed to remove these worksheets from the laboratory.

Although students worked together in groups of two to three (maximum four), however each student had to complete his/her own worksheet. The practical work of the control and experimental groups was, as far as possible, assessed according to the same general guidelines. ERQs carried marks for both groups and they were also used as one of the data sources (see Section 3.6.3).

Since the control and experimental worksheets were different, except for the ERQs on NOS, only the data from the ERQs on NOS was collected.

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1.8.2 Pilot study

An earlier study was done with the first-year students during the first term of 2014 by changing selected traditional physics practical activities to inquiry-based format as part of an intervention by the Physics Department at the University of Pretoria. All groups of students performed the same practical activities during the earlier trial study. The results from this study showed that few students could work with guiding questions without encountering any difficulty. Furthermore, there were many students who constantly needed assistance when working on the assigned tasks in the practical activities. Initially many students were confused and frustrated in learning while conducting inquiry-based laboratory practical activities (NRC, 2000; Weiss, Pasley, Smith, Banilower & Heck, 2003). However, students started to enjoy the inquiry-based practical activities after completing a couple of practical activities. Experience regarding the performance of students, in the earlier trial study, was used when designing the practical activities for the main study.

With regard to the VNOS-C pre/post-test, in a previous trial done before this study, clear signs of test familiarity / test fatigue were observed, in that students often answered the VNOS questions in the post-test with significantly less detail than they did a year before. This was also observed in the study conducted by Baloyi, Meyer and Gaigher (2016) on the development of views on the nature of science of learners in a science enrichment programme.

1.8.3 Training of laboratory assistants

The responsibilities of laboratory assistants were formulated using the guidelines from the AAPT (Feynman, 1998), NSES (NRC, 1996), and Wenning (2011). In addition, the corresponding students' actions that characterised the inquiry-based approach were designed using the guidelines by Van Heuvelen, Allen, & Mihas (1999) and Wenning (2011). The laboratory assistants' responsibilities and students' actions are listed in the Table 1.3, below.

1.9 Discussion of the design of the intervention

One of the rationales behind combining explicit reflective guiding questions and GI, in this study, was to encourage the development of students' thinking skills, motivation and self-efficacy beliefs while conducting practical activities. The development of thinking skills may result in the development of learning goals. These include improving students' understanding of NOS, students' academic performance and attitudes towards the laboratory work.

Numerous studies explored factors that caused undergraduate students to lose interest in science. For example, Seymour and Hewitt (1997, p.180) showed that, "One serious cause of loss of interest was disappointment with the perceived narrowness of their [science, math and engineering] majors as an educational experience…" Additionally, Tobias (1990, p.81) concluded from an interview, conducted with a group of students, that "They hungered—all of them—for information about how the various methods they were learning had come to be, why physicists and chemists understand nature the way they do, and what were the connections between what they were learning and the larger world." Most talented students lose interest in science because of wrongly conceptualising it as only logical, unemotional and an algorithmic process divorced from human influence. These deeply held misconceptions by students may cause them to change their direction of study, a tendency that, according to Tobias (1990), should be addressed.

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Table 1.3 The laboratory assistants' responsibilities and the corresponding students' actions in the ERGI laboratory practical activities.

Laboratory assistants' responsibilities	Students' actions
Encourage inquiry-based practical activities that are student-centred (laboratory assistants should assist students with building on new knowledge from their prior knowledge/experiences; students should be actively involved in performing practical activities and be assisted to construct meaning from their experiences).	Design an experimental procedure of addressing the given guided questions.
Suggest several guiding questions that will support students' thinking and questioning or reasoning skills. They should not provide the students with a straight forward answer to a problem.	Observe different physical phenomena and collect data.
Encourage debate and group discussions among students.	Formulate hypotheses based on their observations and conducting inquiry-based practical activities to validate their conclusions.
Present students with a variety of levels and paths of investigations.	Identify independent and dependent variables, respectively, and establish meaningful relationships between them.
Act as facilitators, mentors and provide as little guidance as possible.	Establish the cause and effect relationships.
Be interested in students' inquiry-based activities and encourage active pursuit for new scientific knowledge and ideas.	Drawing of and interpretation of graphs.
Should not act as the only source of information to students.	Interpretation of data and formulation of conclusions.
Promote a classroom atmosphere that is conducive to inquiry-based activities.	Defending their findings in the light of existing theories.
Encourage students to be interested in learning how knowledge is constructed rather than to know what must be learnt in inquiry-based physics practical activities.	Presentation of their findings in their practical activity worksheets.
Work patiently with students and address all students' problems that contribute to inquiry-based practical activities.	

In the current study, students were encouraged to work in small groups. Moreover, discussions within groups and between groups, as well as interactions between students and laboratory assistants, were encouraged throughout all the sessions of practical activities. This contributed to the shaping of communication and instilling confidence as a result of verbal persuasion (Bandura's (1977) third source of knowledge for self-efficacy). Collaborations between different groups of students and laboratory assistants were also intended to encourage sharing of views and experiences that may result in the deep mastery of physics concepts being investigated in practical activities. Additionally, students were also encouraged to see the learning process as a collective rather than an individual endeavour.

The use of guiding questions in the practical activities together with Socratic guidance by laboratory assistants was meant to change students to self-regulated learners and to realise

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that they had to take responsibility for their own learning. The learning method, used in this study, considered the use of cognitive conflict (Johnson & Johnson, 1998), social interaction (Vygotsky, 1997, 1978), situated learning (Lave & Wenger, 1991) and Socratic guidance (Arons, 1993). Hence, in this study group, interactions and Socratic dialogue enhanced conceptual understanding as well as self-efficacy (Bandura, 1977). Desouza and Czerniak (2003) stated that verbal persuasion, as a result of peer interactions, promoted positive attitudes towards students participating in cooperative reflective activities.

During the ERGI laboratory practical activities students were seen to develop identities as physics students and learning how to behave as physicists. In other words, all students were creating a localised physics student community which was guided by the principles of the broader physicist community of practice. While students were working collaboratively in their small groups they were producing and reproducing the customs for being physicists as they helped each other to address physics problems. According to Sfard (1998), students, while engaged in the learning process, also fulfilled two other processes of participating and negotiating identities. In the words of Sfard (1998, p.6):

> *"…learning a subject is now conceived of as a process of becoming a member of a certain community. This entails, above all, the ability to communicate in the language of this community and act according to its particular norms. The norms themselves are to be negotiated in the process of consolidating the community".*

From the community of practice's perspective learning is not only recognised as the acquisition of science knowledge, skills and norms but it is also seen to be about developing an identity (Holland & Lave, 2009; Lave *et al.*, 1991). When students and laboratory assistants were participating in the ERGI laboratory practical activities, they also contributed to causing the practice to be what it is, thus, "our experience and our membership inform each other, pull each other, and transform each other" (Wenger 1998, p. 96). The learning process also affects the entire individual including how an individual relates to various activities (Lave *et al.*, 1991). The new acquired identity may shape what you know, hence, according to Lave (1996) knowledge is believed to emerge from an action and not something that an individual possesses. As a result conducting the ERGI laboratory activities may not be understood as separate entities. According to Brickhouse (2001, p. 286)

> *"Learning is not merely a matter of acquiring knowledge, it is a matter of deciding what kind of person you are and want to be and engaging in those activities that make one part of the relevant communities".*

In the light of the above discussion, it was assumed that the different aspects of the intervention were developing as predicted in the literature.

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Chapter 2: Literature review

In this chapter, the literature relevant to inquiry-based science education is discussed. This will be followed with the discussions of theories of learning that inform the current study. Research findings that indicate possible benefits of redesigning the traditional physics laboratory into inquiry-based format are discussed. Moreover, the barriers to implementation of inquiry will be discussed. Lastly, there will be a brief discussion of a conceptual framework that arises from these considerations.

2.1 The role of inquiry in science education

The main goal of science education reforms in the US has been and still is for teachers to assist students to develop an informed understanding of SI and NOS (NGSS, 2013; NRC, 2012; Feynman, 1998). Thus, science teachers have the responsibility of teaching students scientific literacy. However, teachers themselves are expected to have developed the informed understanding of SI and NOS that they should teach students. In other words, science teachers should have developed "an understanding of the nature of science including an understanding of scientific nomenclature, intellectual process skills, rules of scientific evidence, postulates of science, scientific dispositions, major misconceptions about science, and unifying concepts and processes of science" (American Association of Physics Teachers [AAPT], 2009, p.17). Informed views of SI and NOS are therefore crucial for the accomplishment of scientific literacy (Bybee, 1997; De Boer, 1991). The AAA (1990) and NRC (1996) endorsed the belief that inquiry is fundamental to the development of scientific literacy. NSES has stated, "students should develop an understanding of what science is, what science is not, and what science can and cannot do" (NRC, 1996, p. 21).

2.1.1 Role of scientific literacy in science learning

The aim of teaching NOS is to improve scientific literacy (Lederman, 2007; Lederman, Antink & Bartos, 2012; Millar, 2006). The understanding of NOS is part of scientific literacy for it "will enable students (and the general public) to be more informed consumers of science" (Lederman, 1999, p. 916). Abd-El-Khalick and BouJaoude (1997, p.1) asserted that, "A scientifically literate person should develop an understanding of the concepts, principles, theories and processes of science, and an awareness of the complex relationships between science, technology and society". The National Science Education Standards (NRC, 1996, p. 22) defines scientifically literate citizens as individuals who, "can ask, find, or determine answers to questions derived from curiosity about everyday experiences" and who can "describe, explain, and predict natural phenomena".

In literature, many definitions for scientific literacy have been used. Anderson (2007) posited that scientific literacy is a science construct associated with scientific knowledge, values and practices which students should acquire as they learn science. Bybee (1997, p.69) posits that: "The phrase 'scientific literacy for all learners' expresses the major goal of science education

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– to attain society's aspirations and advance individual development within the context of science and technology". Scientific literacy "stands for what the general public ought to know about science" (Durant, 1993, p. 129), and "commonly implies an appreciation of the nature, aims, and general limitations of science, coupled with some understanding of the more important scientific ideas" (Jenkins, 1994, p. 5345).

Subsequently, scientific literacy is believed to be important for the development of the ability of lay people to understand science that affects their daily lives (DeBoer, 2000; Laugksch, 2000; Linder, Ostman & Wickman, 2007; Roberts, 2007; Songer, Lee & McDonald, 2003). One advantage of this emphasis is a belief that individuals may participate in debates involving socio-scientific issues (Feinstein, 2011; Lederman, 1999; Millar & Osborne 1998; OECD 2006; Shwartz, Ben-Zvi & Hofstein, 2005). Munby (1982, p.31) endorsed science instruction that supports "intellectual independence" and affords students with "all the resources necessary for judging the truth of knowledge independently of other people". Furthermore, public understanding of NOS is important for democracy, since people should make informed scientific and technological decisions in life (NRC, 2012; Norris, 1992). Scientific literacy offers individuals the means to utilise and formulate decisions that may address complex socio-scientific issues (Fowler, Sadler & Zeidler, 2009).

There is considerable research that indicates the importance of learning about NOS. For instance, Carey and Smith (1993, p. 235) state that development of learners' understanding of NOS may enhance, "lifelong learning, and a valuing of the kind of knowledge that is acquired through a process of careful experimentation and argument, as well as a critical attitude toward the pronouncements of experts". The same views were also expressed by other researchers (Akerson, Morrison & McDuffie, 2006; Chin, 2005; Clough, 2011; McComas, 2000).

Duit and Treagust (2003, p.680-681) used the work of Driver and Osborne (1998) to advance four reasons for improving all individuals' scientific literacy. These include:

"(1) The economic argument–modern societies need scientifically and technologically literate work-forces to maintain their competencies,

(2) The utility argument–individuals need some basic understanding of science and technology to function effectively as individuals and consumers,

(3) The cultural argument–science is a great human achievement and it is a major contributor to our culture,

(4) The democratic argument–citizens need to be able to reach an informed view on matters of science-related public policies in order to participate in discussions and decision-making."

Despite on-going calls emphasising the importance of NOS as a fundamental feature of scientific literacy (Collette & Chiappetta 1984; Lederman 1992; Matthews 1989, 1994), there are few teachers at institutions of higher learning that spend enough time teaching NOS. A comprehensive discussion of the aspects of NOS follows in section 2.3.

2.1.2 What is inquiry?

The term 'inquiry' is widely used in the literature and there is variety of overlapping interpretations by different scholars (Duschl & Grandy, 2008). In the current study the

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spelling "inquiry" preferred by US scholars such as Schwartz, Lederman and Lederman (2008); Akerson, Hanson and Cullen (2007); Clough (2007) and Lederman and Lederman (2004) is used instead of "enquiry" which is preferred by the UK scholars. Given the range of different conceptions of inquiry, it is no surprise that Lunetta, Hofstein, and Clough (2007, p.396) highlighted an ambiguity associated with the term "inquiry":

> *"The understanding of 'inquiry' has been further complicated by use of terms such as "inquiry science teaching" which may refer to teaching science as inquiry (helping students understand how scientific knowledge is developed) or teaching science through inquiry (having students take part in inquiry investigations to help them acquire more meaningful conceptual science knowledge".*

Inquiry-based science teaching is broadly defined by Blanchard *et al.*, (2008) as teaching which focuses on knowledge attainment and development. Inquiry-based science teaching at high school level in the USA has recently been extended by the Next Generation Science Standards (NGSS) to include interdisciplinary inquiry as a form of teaching (Nargund-Joshi & Liu, 2013; NRC, 2012). Since the NGSS outlines learning outcomes that combine science practices, cross-cutting concepts, and core ideas (NGSS Consortium of Lead States, 2013), teaching science as inquiry and by inquiry should be implemented in all levels of science teaching. The NGSS (Achieve, Inc., 2013) and the Framework for K-12 Science Education (NRC, 2012) currently emphasise the use of the term "science practices" instead of "inquiry", thus emphasising that "engaging in scientific inquiry requires coordination both of knowledge and skill simultaneously" (NRC, 2012, p. 41).

Inquiry has a plethora of meanings across literature. The current study is based on the US science education reform documents, describing three different views of inquiry (Barman, 2002; Bybee, 2000; Hofstein, Nahum, & Shore, 2001). The first meaning of inquiry refers to pedagogical strategies such as designing, measuring students' pre-existing knowledge and facilitating inquiry lessons (NRC 2012, 2000; Piaget, 1970). This strategy includes that teachers are encouraged to ask open-ended questions that promote critical and creative thinking by students and support collaborative learning. The second meaning of inquiry refers to engaging in the processes of scientific inquiry. Students should learn to conduct scientific inquiry (NRC, 1996). Scientific inquiry skills include asking and identifying questions (Bereiter & Scardamalia, 1989), planning and designing experiments (Schauble, Glaser, Duschl, Schulze, & John, 1995), collecting and analysing data (Hancock, Kaput & Goldsmih, 1992; Vellom & Anderson, 1999), and connecting evidence with explanations (Chinn & Brewer, 1993). The third meaning of inquiry refers to cognitive understanding of scientific investigations performed by scientists using a variety of scientific methods. Inquiry is believed to be either a content to be learnt or a skill to be mastered by students. Students should learn how scientists do their work and that they use multiple scientific methods guided by social and cultural values, imagination and creativity as well as expertise in their fields of research (Lederman *et al.*, 2002). In other words, understanding of inquiry would provide students with an opportunity to understand the theoretical as well as social and historical factors of scientific inquiry and NOS (Hofstein *et al.*, 2001).

On the other hand, Duschl and Grandy (2008) emphasised the acceptable understanding of inquiry instruction which indicates that science teaching should include three connected frameworks of science learning. These include: (a) cognitive frameworks, which describe how scientific knowledge is generated, (b) epistemic frameworks to evaluate scientific knowledge, and (c) social frameworks describing how cultural aspects influence scientific

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discoveries. Additionally, Duschl and Grandy maintained that aforementioned frameworks should be integrated to an extended inquiry instruction.

Schwartz *et al.* (2004, p.612) argue that scientific inquiry "refers to characteristics of the scientific enterprise and processes through which scientific knowledge is acquired, including the conventions and ethics involved in the development, acceptance, and utility of scientific knowledge". On the other hand, the National Science Teachers Association describes scientific inquiry as follows:

> *"Scientific inquiry is a powerful way of understanding science content. Students learn how to ask questions and use evidence to answer them. In the process of learning the strategies of scientific inquiry, students learn to conduct an investigation and collect evidence from a variety of sources, develop an explanation from the data, and communicate and defend their conclusions" (NSTA, 2004, p. 1).*

Linn *et al.* (2004, p. 4) described inquiry instruction as "engaging students in the intentional process of diagnosing problems, critiquing experiments, distinguishing alternatives, planning investigations, researching conjectures, searching for information, debating with peers, seeking information from experts, and forming coherent arguments." On the other hand, Abd-El-Khalick *et al.* (2004), differentiated between the terms "inquiry as means" (or inquiry in science) and "inquiry as ends" (or inquiry about science). According to these researchers' descriptions of scientific inquiry, "inquiry as means" refers to "inquiry as an instructional approach intended to help students develop understandings of science content" (Abd-el-Khalick *et al.,* 2004, p.398). In other words, "inquiry as means" refers to when science teachers use inquiry as a teaching approach to assist students to acquire a notion of science cross-cutting concepts and core ideas (Levy, Thomas & Drago, 2013).

In addition, 'inquiry as ends' refers to "inquiry as an instructional outcome" intended to assist students to "learn to do inquiry in the context of science content and develop epistemological understandings about the nature of science and the development of scientific knowledge, as well as relevant inquiry skills such as identifying problems, generating research questions, designing and conducting investigations, and formulating, communicating, and defending hypothesis, models, and explanations" (Abd-el-Khalick, *et al.*, 2004, p. 398). Put differently, "inquiry as ends" refers to when science teachers focus students' learning about the practices of science (Levy *et al.*, 2013). Furthermore, Abd-el-Khalick *et al.* (2004) argued that the different features of scientific inquiry were initially neglected in the US because of the belief that students may automatically acquire an understanding of these features when participating in inquiry-based activities. However, Lederman and Abd-El-Khalick (1998) argue that students' understanding of different aspects of NOS may not develop spontaneously, as a result teachers should explicitly teach NOS to enable students to develop an informed understanding of NOS.

Chiappetta (1997) classified inquiry-based approaches into two main categories: the general inquiry and scientific inquiry. The former is broad and it is sometimes referred to as an open approach/ teaching-science-by-inquiry / teaching science through inquiry and learning by discovery. The general inquiry went through a number of modifications during the post-Sputnik era of science education reforms and focused on students' attitudes, reasoning skills, and habits of mind. The latter (also referred to as teaching science as inquiry / scientific inquiry) is specifically limited to scientific content only. The US NSES (NRC, 2000;

Lederman, Lederman, Bartos, Bartels, Antink & Schwartz, 2014; NRC, 2012) described eight important features that students should be taught:

(1) All scientific investigations should start with a question but the question does not always get used for hypothesis testing.

(2) There is not one universal step-by-step procedure followed by all scientists when conducting investigations,

(3) The process of inquiry is determined by the formulated research question,

(4) Scientists using the same experimental methods may not arrive at the same results,

(5) Inquiry processes may have an effect on the final results,

(6) Conclusions should be drawn from the gathered data,

(7) Scientific data is different from the scientific evidence and

(8) Conclusions are derived from the data in the light of existing theories.

The NRC in *National Science Education Standards* describes scientific inquiry as follows:

> *"Scientific inquiry refers to the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Inquiry also refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world" (NRC, 1996, p. 23).*

According to the NSES

> *"Inquiry is a multifaceted activity that involves making observations, posing questions, examining books and other sources of information to see what is already known, planning investigations, reviewing what is already known in light of experimental evidence, using tools to gather, analyze, and interpret data, proposing answers, explanations, and predictions, and communicating the results" (NRC, 1996, p. 23).*

The American Association for the Advancement of Science Project 2061 in the *Benchmarks for Science Literacy* (AAAS, 1993, p. 9) describes inquiry slightly differently to the NRC (1996):

> *"Scientific inquiry is more complex than popular conceptions would have it. It is, for instance, a more subtle and demanding process than the naive idea of 'making a great many careful observations and then organizing them.' It is far more flexible than the rigid sequence of steps commonly depicted in textbooks as 'the scientific method.' It is much more than just 'doing experiments,' and it is not confined to laboratories. More imagination and inventiveness are involved in scientific inquiry than many people realize, yet sooner or later strict logic and empirical evidence must have their day. Individual investigators working alone sometimes make great discoveries, but the steady advancement of science depends on the enterprise as a whole".*

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Although inquiry-based instruction should not be regarded as the only acceptable teaching strategy, this approach reveals to students a learning style that resembles how scientists work (Capps & Crawford, 2013). Inquiry promotes deeper conception of science and supports the development of critical thinking skills. Also, inquiry-based instruction provides a learning environment which promotes understanding of NOS (Carey & Smith, 1993; Schwartz *et al.*, 2004).

In inquiry-based learning students are presented with a problem to solve and in the process of addressing that problem, students may accomplish the required learning outcomes (Barrows, 2000). However, there is some disagreement in literature about whether or not inquiry does actually support academic performance. On one hand, literature indicates that the academic performance of medical students engaged in problem-based learning decreased marginally on standardised examinations (Albanese, & Mitchell, 1993; Vernon, & Blake, 1993). While other research studies have shown that inquiry-based approaches had a small positive effect on students' academic achievement in examinations (El-Nemr, 1980; Lott, 1983). In contrast, literature indicates that the inquiry-based approach has been more efficient than traditional instruction in advancing academic performance and developing thinking skills, problem-solving skills as well as laboratory skills (McReary, Golde & Koeske, 2006; Oliver-Hoyo & Allen, 2005; Oliver-Hoyo & Beichner, 2004; Rubin, 1996).

Inquiry-Based Science Education (IBSE) is also believed to be one of the teaching and learning approaches that supports intrinsic motivation of students (Trna & Trnova, 2006). IBSE originated from the deep conceptualisation of the scientific practice and processes (Narode *et al.*, 1987). The fundamental principles of IBSE include realising natural laws, applying information into real-life contexts, enhancing critical thinking, and developing positive attitudes towards science learning (Kyle, Bonnstetter, McCloskey & Fults, 1985; Rakow, 1986).

2.1.3 Continuum of inquiry

The NRC (2000) categorises inquiry into full and partial enquiries in terms of what students should do in classroom inquiry. In full inquiry students independently formulate their own "scientifically oriented questions", "give priority to evidence in responding to questions", "formulate explanations from evidence", "connect explanations to scientific knowledge" and "communicate and justify explanations" (NRC, 2000, p. 29). In partial inquiry or GI a teacher continuously directs all the activities (McDermott, 1996; Trowbridge, Bybee & Powell, 2004).

Banchi *et al.* (2008) categorised inquiry into four levels, namely, (1) confirmation inquiry, (2) structured inquiry, (3) GI and (4) open inquiry (refer to Table 2.1). These levels were formulated to guide teachers in scaffolding students' inquiry activities (Bell *et al.*, 2005; Cothran *et al.*, 2000).

In all levels of inquiry students are engaged in scientific practices, but the type of scaffolding depends on what students should learn on their own versus the assistance provided by the teacher. Confirmatory inquiry is a structured type of inquiry, where students are given the investigative questions, the methods, and the solutions. Usually confirmatory inquiry is done after the content has been taught and students are required to confirm a theory or law. In structured inquiry, students are given the investigative question and methods, they analyse and interpret data to formulate an answer to the research question. This type of inquiry is

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Table 2.1 Four levels of IBSE (Banchi *et al.*, 2008).

IBSE levels	Questions	Procedure	Solution
Open inquiry	formulated by student	developed by student	discovered by student
Guided inquiry	defined by teacher	developed by student	discovered by student
Structured inquiry	defined by teacher	defined by teacher	discovered by student
Confirmation inquiry	defined by teacher	defined by teacher	given by teacher

usually initiated by a teacher and tends to be structured inquiry (level 2) since students have less intellectual ownership (Capps *et al.*, 2013).

GI is an inquiry where students are given the investigative question, but students should design a plan of addressing the research question. GI is a process of discovery and discourages rote memorisation which is soon forgotten. By the asking of high level intellectual guiding questions or open-ended questions while performing a practical investigation, that should create a dialogue between students and their instructors (Duschl, 2000, 2008), a deeper level of understanding is achieved. In the investigation process, students use their prior knowledge as a breeding ground to link new knowledge with their existing concepts. Through open group discussions and interactions with science instructors, students' misconceptions may be identified and addressed. It is also essential for an instructor to develop students' abilities to formulate further investigative questions, to explore and allow them time to construct a new body of knowledge. It is generally believed that effective learning of science content may occur when GI practical activities are conducted prior to the learning of content in a lecture (Jarret, New & Karaliolios, 1997). Open inquiry is a type of inquiry where students formulate their investigative questions and design investigations for addressing these questions. In this type of inquiry students have a maximum intellectual ownership in their investigations.

2.1.4 Inquiry-based Instruction versus Traditional Instruction

The lecture method is one of the oldest traditional teaching approaches which are followed in science instruction (Braxton, 2008; Einarson, 2001; Hrepic, Zollman & Rebello, 2007). The traditional approach is even used in the undergraduate teaching of physics in many universities (Hertado, Eagan, Pryor, Whang & Tran, 2012; Hrepic *et al.*, 2007). This teacher-centred approach sees learning as the transferral of information, where students are treated as passive receivers of knowledge. The teaching in a traditional classroom assumes that knowledge is outside of the student, objective and should be transmitted from teacher to learners (Friere, 1970; Tobin, Briscoe & Holman, 1990).The traditional lecture method is also referred to as direct instruction or explicit teaching as basic skills, facts, and information are presented to students by the teacher (Woolfolk, 2007). Because of their own experiences, many teachers use the direct instruction and students have adapted to this teaching method (McBride *et al.*, 2004).

Traditional lecture instruction relies mainly on following the curriculum which supports surface learning like memorisation (Briscoe & LaMaster, 1991; Mason, 1992; Pressley & Woloshyn, 1995). The curriculum is usually perceived as a fixed collection of facts which do not promote higher order thinking skills (McBride *et al.*, 2004). In other words, the lecture method put more emphasis on the content rather than on the thinking skills (Drayton *et al.*, 2001). Additionally, the use of standardised tests supports the belief that students should be taught the already established knowledge instead of constructing their own knowledge. Thus, the instructor lectures, and the students memorise the material covered in class in preparation for the examination (Hernandez, 2002).

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On the same note, the US high school education system was criticised as it could not assist students to learn the 21st century skills of critical thinking which may enable them to critically analyse science-based 21st century problems (Butrymowicz, 2012). According to Butrymowicz, the US students in the early grades memorise facts while students in other countries such as Finland, Japan and Korea learn foundational concepts that simplify understanding of the complicated processes in the later grades. To develop better understanding of the subject content, students should be taught the fundamentals of inquiry. Butrymowicz further asserted that US students' lack of success in science was because of adhering to the step-by-step procedure during investigation instead of encouraging students to think critically about the science content.

An analysis of 138 research studies on inquiry-based learning between 1983 and 2002 by Minner, Levy and Century (2009), has shown that grade K-12 students who were taught concepts through student-driven scientific investigations performed better in state standardised tests than students who received teacher-centred instruction. Thus, the focus of teaching should be more about how content is delivered rather than on the quantity of content that could be covered in a year.

Physics Education Research (PER) studies shows that the traditional lecturing approach does not develop the essential students' learning outcomes (Bligh, 2000; Einarson, 2001; Haynes, 1999; Liu, 2006; van Zee, Hammer, Bell, Roy & Peter, 2005). These studies reveal that lecturing does not encourage students to critically engage with the science content and it leads to rote learning (Kalman, 2002; Kubli, 2001; Stinner, 2006). In a traditional learning environment, students are shown physics as a rigid body of knowledge and formulae not linked to human endeavour (McBride *et al.*, 2004; Pressley *et al.*, 1995; Smith *et al.*, 1999). Teachers usually focus students' attention on solving quantitative problems (White, 1993). Students are rarely given problems that may encourage them to involve their higher order thinking skills when solving a problem. Instead, teachers provide the students with the right answers (Pressley *et al.*, 1995). Direct instruction encourages students to memorise an algorithm for addressing a problem without developing an understanding of knowledge (Pressley *et al.*, 1995; White, 1993).

A study by Doucet, Purdy and Langille (1998) showed that in a traditional lecture environment, the teacher imparts information while students are treated as passive recipients of knowledge. Peek, Winking and Peek (1995) argued that the lecture approach is preferred by many lecturers because it is perceived as a way of maintaining discipline in class. In addition, a lecture method may be used by lecturers who are not familiar with other teaching strategies. The traditional lecture is usually used by lecturers when a large quantity of information is to be disseminated to students (Peek *et al.*, 1995). Moreover, the development of lecturing materials that are used in a lecture environment have assisted lecturers to attain students' attention (Cardoso *et al.*, 2009).

Previous research shows that students start a formal physics course with alternative perceptions which are in contrast with those of the physicists (Halloun & Hestenes, 1987; McDermott, 1984; Wandersee, Mintzes, & Novak, 1994; Wiser & Amin, 2001). Usually many students have a variety of misconceptions because the physics concepts are abstract and not directly observable. For instance, concepts such as heat and temperature are not directly observable (Harrison, Grayson & Treagust, 1999) and they are difficult for students, the public and scientists to conceptualise (Lewis & Linn, 2003). These misconceptions are common sense beliefs about the world which are strongly held by students due to their own

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experiences (Norvilitis, Reid & Norvilitis, 2002; Pajares, 1992; Cobern, 1993). A deep-seated belief is connected to the other beliefs in the belief system, is strengthened by experience, and can explain observations and supports strong personal or social goals (Chinn & Brewer, 1993). Research has further demonstrated that traditional instruction is mainly unsuccessful in transforming students' alternative views which are persistent and are resistant to change (Eryilmaz, 2002).

Many science educators (Clement, 1982; diSessa, 1982; Dykstra, Boyle, & Monarch, 1992; Gunstone, 1987; McClosky, 1983; Wandersee, *et al.*, 1994) argued that misconceptions of mechanics in physics classroom or physics laboratory are unlikely to be changed by the traditional lecture approach. For example, trying to persuade students with scientific arguments based on Newton's laws is not effective in changing students' misconceptions since such teaching cannot transform students' beliefs. This may easily be understood since students develop beliefs informed by their understanding of reality, embedded in their pre-existing knowledge and experiences. Pajares (1992) posits that beliefs are acquired throughout an individual's life experiences and are difficult to change. Subsequently if students do not establish links between new experiences and their prior knowledge, then new knowledge may not be internalised (Bruning, Schraw, Norby & Ronning, 2004; Cobern, 1993). Put differently, misconceptions create an obstacle towards attaining a meaningful understanding of targeted physics concepts (Novak, 2002). Students' beliefs conflict with the accepted scientific perspectives (Pressley *et al.*, 1995). Consequently, students should be actively involved in the interpretation and internalising of new experiences for effective learning to occur (Kruckeberg, 2006; Palincsar, 1998; Watson, 2001).

Some students may be comfortable with the teacher centred approach which promotes the learning of science as a fixed body of content (Garvin & Ramsier, 2003). However, other students may find direct instruction discouraging as it does not develop their deeper understanding of science nor does it relate in class science knowledge with real-life experiences (Smith *et al.*, 1999). This is a drawback of the lecture method to the academically successful students because learning is superficial and is quickly forgotten (Brass, Gunstone, & Fensham, 2003). Many students have alternative views about the application of physics to everyday phenomena, although they have passed a physics course (Norvilitis *et al.*, 2002). For instance, students who passed their physics well either at high school or college level may find it difficult to describe the path of a falling object (Norvilitis *et al.*, 2002; White, 1993). This occurs because, students start the course with internalised misconceptions (Norvilitis *et al.*, 2002).

Trumbull, Bonney and Grudens-Schuck (2005) argue that current science textbooks persist to promote the perception of science knowledge as unchanging. Such presentations inhibit students from understanding NOS, as well as contradictions and disagreements among scientists. In addition, scientific knowledge being portrayed as an established body of knowledge does not encourage students to conduct their own investigations and make their observations of the natural world. Furthermore, this may hinder students' ability and confidence in inquiry. Consequently, students who lack experience in inquiry find it hard to articulate research questions, design an investigation plan to gather scientific evidence, analyse and interpret data, and formulate conclusions justified with empirical evidence. However, it is believed that through the implementation of inquiry-based instruction as proposed by science education reform documents, the shortfalls of traditional teaching may be eradicated. The National Science Education Standards (NRC, 1996) promotes the use of scientific inquiry. "This standard cannot be met by having the students memorize the abilities

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and understandings. It can be met only when students frequently engage in active inquiries" (NRC, 1996, p. 143).

There are several studies that suggest that inquiry promotes student achievement on tests of procedural knowledge (Glasson, 1989), and impoves students' attitude towards science (Kyle *et al.*, 1985; Palincsar, 1998; Pressley *et al.*, 1995; Rakow, 1986; Supovitz, Mayer & Kahle, 2000). In addition, inquiry-based instruction enhances scientific literacy and scientific process skills (Lindberg, 1990). Inquiry empowers students to use different scientific methods and processes employed by scientists when performing problem-based investigations (McBride *et al.*, 2004). Inquiry-based learning is underpinned by the experiential learning theory which investigates how "knowledge is created through the transformation of experience" (Kolb, 1984, p. 38). The theory of experiential learning posits that learning through experience promotes a deeper understanding than other learning methods (Kolb & Fry, 1975). Kuhn, Black, Keselman and Kaplan (2000, p.496) argued that students performing an inquiry activity "come to understand that they are able to acquire knowledge they desire, in virtually any content domain, in ways that they can initiate, manage, and execute on their own, and that such knowledge is empowering".

Inquiry-based teaching approaches use a range of teaching strategies that involve a student as an active agent in the knowledge construction rather than passive recipient of information (Loyens & Rikers, 2011). Inquiry encourages student-centred approaches and uses instructional practices such as observations, formulating questions, realising gaps in one's knowledge base and conducting investigations to close the gaps. Traditional teaching approaches promote transmission of researched knowledge to students, while student centred approaches like inquiry inspire students to construct knowledge by engaging in investigative activities. Additionally, it is believed that learning by conducting investigations is conducive to students understanding of how knowledge is generated (Gibbs, 1988). Inquiry-based teaching helps students to use a deep approach to learning whereas the traditional teaching method encourages students to use a superficial approach (Biggs 2003; Brew & Boud, 1995; Prosser & Trigwell, 1999).

Research conducted by Magolda (1999) and Blakemore and Cousin (2003) shows that students engaged in research-based inquiries developed a higher-level of understanding. According to Magolda (1999, p.9) a research-based inquiry is described as "constructive development pedagogy … (in which) teachers model the process of constructing knowledge in their disciplines, teach that process to students, and give students opportunities to practice and become proficient at it".

2.1.5 Role of argumentation in guided inquiry

Interactions amongst individual students and between groups are crucial for effective learning (Reid & Skryabina, 2002). Collaborative learning shows "more resemblance to the scientific workplace than to the usual traditional teaching environment" (Thornton & Sokoloff, 1990, p. 866). Gunstone and Champagne (1990) contended that a laboratory provides both students and teachers with opportunities to participate in collaborative inquiry and to work as a group of researchers would. Learning of physics concepts may be improved if group discussions between students are encouraged (Watson, Swain & McRobbie, 2004). Successful learning may arise between open-minded groups which are willing to exchange views and reach a negotiated conclusion (Alexopolou & Driver, 1996).

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Munford and Zembal-Saul (2002) and Zembal-Saul (2005) indicate that there are multiple benefits for students when they are engaged in learning environments that encourage them to participate in argumentation. Students may be presented with scientific practices that they could use to construct knowledge in different contexts. Additionally, students may learn science content and understand the influence of language, cultural and group interaction in the development of science knowledge (Brown, Collins & Duguid, 1989; Driver, Newton & Osborne, 2000; Erduran & Jimenez-Aleixandre, 2008). When students are participating in argumentative discourse teachers may be able to understand students' ideas and reasoning and provide necessary guidance for self-evaluation and discussion (Abell, Anderson & Chezem, 2000; Bell & Linn, 2000; Zembal-Saul & Land, 2002). This discussion enhances the development of various students' thinking/reasoning skills (Kuhn, 1991, 1993) and their insights in scientific concepts (Zohar & Nemet, 2002). The NRC (2006) proclaimed that there are seven goals in science learning for students which should be encouraged in the laboratory. These include:

> *"enhancing mastery of subject matter, developing scientific reasoning, understanding the complexity and ambiguity of empirical work, developing practical skills, understanding the nature of science, cultivating interest in science and interest in learning science, and developing teamwork abilities" (NRC, 2006, pp. 76 –77).*

Current perceptions in the philosophy of science (Giere, 1991; Kitcher, 1988) suggest that science should not be understood as a simple accumulation of facts regarding the natural world. Instead science ought to be understood as the development of theories that account for how varieties of world phenomena work. In the process of formulating explanations for different natural phenomena, theories are challenged and rejected (Popper, 1959). Sometimes science knowledge develops because of disagreement, conflict and argument rather than through consensus (Kuhn, 1970; Latour & Woolgar, 1986). Put differently, scientists are always engaged in dialogue regarding the importance of experimental design, the understanding of empirical evidence and the trustworthiness of knowledge. Scientists always engage in argumentations and argumentation is perceived as a mechanism of maintaining control within the scientific community (Kuhn, 1992). From a sociocultural view on cognition, engaging in discussions teaches students skills such as scientific dialogue, which are practised in the scientific community (Kelly & Chen, 1999).

Driver *et al.* (2000, p.291) emphasise that dialogic argumentation takes place "when different perspectives are being examined and the purpose is to reach agreement on acceptable claims or courses of actions". Dialogic argumentation involves groups of individuals exchanging views in order to achieve agreement on the validity of their alternative views. Through the use of dialogic argumentation students "articulate reasons for supporting a particular claim, attempt to persuade or convince their peers, express doubts, ask questions, relate alternate views, and point out what is not known" (Driver *et al.*, 2000, p. 291). Additionally, through dialogic argumentation students "… can reflect on their own ideas and the ideas of others, aiding them in addressing misconceptions and developing better understandings" (Cross, Taasoobshirazi, Hendricks & Hickey, 2008, p. 839).

Bricker and Bell (2009) classified argumentation as the fundamental way in which knowledge in science is developed. Subsequently, Bricker *et al.* (2009) claim that the aim of science instruction does not only involve the mastering of scientific concepts but also developing communication skills to participate in scientific discourse. Moreover, students

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should view science as a process, in which scientific claims are established, reviewed, frequently revised or modified (Diehl, 2000). Dewey (1934, p. 76) describes transformation and development of knowledge as "reorganizing or reconstruction of experience". When students are performing scientific investigations, they may engage in argumentation which may encourage them to think critically about what they might be investigating. Negotiations of meanings amongst students may result in some students changing their deeply held view of prior knowledge regarding the idea being investigated.

Other research studies explored the effect of argumentative discourse on students' understanding of science concepts (Aydeniz, Pabuccu, Cetin & Kaya, 2012; Jimenez-Aleixandre & Pereiro-Munhoz, 2002; von Aufschnaiter, Erduran, Osborne, & Simon, 2008; Zohar *et al.*, 2002). These studies demonstrated that students' understanding of concepts was enhanced by argumentation. Additionally, acquisition of several scientific concepts was also related to certain types of argumentative processes. Von Aufschnaiter *et al.* (2008, p.121) claim that, "argumentation supports students' improvement in thinking as the evidence from the students' discourse suggests that it leads to a quicker development of specific ideas and helps to make connections across (familiar) contexts. It is this type of improvement that is the basis of further learning". Students that participate in argumentation discourse understand "scientific inquiry as epistemological and social processes in which knowledge claims can be shaped, modified, restructured, and at times, abandoned" (Duschl, 2008, p. 159). Altogether, this indicates that students' participation in argumentation does not only enhance development of conceptual understanding but their thinking skills may also be enhanced (Kuhn, 1992, 1993; Kuhn, Shaw & Felton, 1997).

However, argumentation in science education may not be equally beneficial to all. When students work collaboratively to address a problem, it is usually believed that learning may occur because of individuals integrating knowledge, different ideas and different cognitive strengths, using an advantage of constructive feedback. There is no reason to assume that the collective team work in resolving a given problem would be equally mastered by all group members. Hatano and Inagaki (1991, p.335) claim that, "pieces of information distributed among members can be used to solve a given problem without being coordinated into a new piece of knowledge in each member's head".

2.1.6 Historical background on inquiry-based teaching and learning

The teaching approaches that engage students in the process of developing knowledge can be found in the history of didactics. The ancient Greeks used dialogue in their teaching where the teacher proposed a problem and assisted a learner to address a problem by asking questions. This teaching strategy can be found in the work of Plato (427-347 BC) where he outlines how Socrates assisted a slavery boy to solve the theorem of Pythagoras (Plato, 1949). This teaching strategy was informed by the perception that a learner possesses essential knowledge that needs to be initiated. Moreover, the teaching principles of Socrates, Plato and Aristotle (470 – 320BC) focus on the epistemology or development of knowledge. Furthermore, the work of Emmanuel Kant (during the late 18th to early 19th centuries) also emphasises the active participation of a learner in the development of knowledge. According to Kant (1959), individuals' faculty knowledge or prior knowledge has an influence in understanding the world around them. Kant (1959, p.25) argues "but though all our knowledge begins with experience, it does not follow that it all arises out of experience".

Science education in the US has changed over the last two centuries from a lecture approach to a learner-centred approach (Redish, 2000). According to the lecture approach, science was

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taught as a rigid body of knowledge to be understood by students and with less emphasis on hands-on activities. An inquiry-based approach provides students with investigations which promote students' deeper knowledge of a natural phenomenon.

John Dewey (1859-1952) was an education reformer, philosopher, and psychologist who led the progressive education movement of the early 1900's. Dewey's extensive work at the University of Chicago Laboratory Schools influenced the educational philosophies of that time. Dewey emerged on the educational scene during the time of struggle as to who should control the American curriculum. The control of the curriculum has shifted from the teacher to the subject matter and from the subject matter to an individual learner. Kliebard (2004, p.1) demonstrated in *The Struggle for the American Curriculum* that "With the change in the social role of the school came a change in the educational centre of gravity, it shifted from the tangible presence of the teacher to the remote knowledge and values incarnate in the curriculum". Dewey (1964, p. 183, first published 1910) posited that,

> *"Science has been taught too much as an accumulation of ready-made material with which students are to be made familiar, not enough as a method of thinking, an attitude of mind, after the pattern of which mental habits are to be transformed".*

Dewey (1910) differed from the rigid method of teaching. According to Dewey, the teaching of science emphasised the rote learning of facts instead of developing thinking skills and changing students' attitudes. At the time, science instruction relied on the rigid scientific method which was comprised of six steps: identifying a problem, describing the problem, formulating a hypothesis, testing the hypothesis, conducting investigations, and formulating a solution. Dewey (1910) described basic inquiry learning format and suggested the use of inquiry in the K-12 science curriculum in the US.

Dewey's (1916) teaching approach encouraged science instruction in which teachers should act as facilitators of the learning process, while students developed an understanding of science concepts. When teaching difficult subject matter, teachers should guide students using students' prior knowledge as a starting point to the anticipated level of understanding. According to Dewey (1916), science teaching should incorporate students' real-life experiences in order for students to expand their personal science knowledge. Dewey (1933) asserted that learning results from the experiences acquired by an individual participating in a process of inquiry. Woolfolk (2004, p.329) asserted that "Inquiry learning is an approach in which the teacher presents a puzzling situation and students solve the problem by gathering data and testing the conclusion…".

The inquiry process is triggered by a puzzling experience of a natural phenomenon that encourages an individual to think reflectively and design ways to address a problem. Reflective thinking promotes incorporating new experiences into an individual's existing knowledge for new knowledge to be constructed. Dewey's views (1936, p.464) about his Laboratory school confirmed that

> *"The underlying theory of knowledge emphasized the part of problems, which originated in active situations, in the development of thought and also the necessity of testing thought by action if thought was to pass over into knowledge. The only place in which a comprehensive theory of knowledge can receive an active test is in the process of education".*

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In addition, the process of inquiry should occur in a learning environment which encourages students to collaboratively work together in the construction of knowledge (Dewey, 1938). Dewey believed that teaching involves constructing interactions between self (learners), other people and the subject matter. Consequently, a teacher should not transmit ready-made knowledge to learners – instead teaching should be at the centre of building links between learners and their peers. In other words, a learner should neither be detached from learning nor from the environment in which learning occurs. Dewey (1938, p.25) argued that inquiry may bring about "an organic connection between education and personal experience". Dewey (1938, p.79) further suggested that teachers should be entrusted with two responsibilities to ensure that the relations between learners and experience are maintained,

> *"First that the problem grows out of the conditions of the experience being had in the present, and that it is within the range of the capacity of students, and secondly, that is such that it arouses in the learner an active quest for information and of production of new ideas".*

Dewey (1938) further argued that students should be actively engaged in learning as science instruction integrates science problems that are relevant to students' experiences and intellectual capability. Dewey (1944) advocated the use of scientific process in science teaching which may result in the development of scientific knowledge. According to Dewey (1944, p.120), "The end of science teaching is to make us aware of what constitutes the more effective use of mind, of intelligence". In addition, Dewey (1944, p.122) posited that,

> *"What is desired of the pupil is that starting from the ordinary unclassed material of experience he shall acquire command of the points of view, the ideas and method, which make it physical or chemical or whatever…the dynamic point of view [is] the really scientific one, or the understanding of process as the heart of the scientific attitude".*

Immediately after Dewey and before the emergence of the Physics Education Research, there were two major thrusts of awareness and outcry that pushed physics laboratory education towards a more inquiry-based format. Firstly, the Union of Soviet Socialist Republics sent the world's first artificial satellite, Sputnik 1, into space in October 1957 (Chiapetta, 1997), followed by the race to space and Cold War politics (Rudolph, 2002). This event was the major stimulant in transforming science and maths curricula in the American higher education (Brainard, 2007). In addition, the launch of Sputnik 1 was a point indicator to the Americans that their education system could not compete with the Russian technological advances (Brekke, 1995). This prompted the American people to re-evaluate both the quality of the science curriculum and of science teachers in American high schools. The scientific superiority of the Soviet Union forced the United States of America to change their high school science curriculum. The curriculum was transformed from traditional cookbook instruction to an inquiry-based approach on the assumption that it would promote the development of thinking skills (Watson *et al.*, 2004).

Schwab (1960) distinguished between two kinds of inquiry: stable inquiry (expanding knowledge) and fluid inquiry (development of new theories that change science knowledge). Schwab further argued that science teaching should be similar to the manner in which modern

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science operates. Integral to the way modern science works, Schwab suggested laboratory work to assist students in conceptualising science. Moreover, Schwab suggested that students should read previous research reports and books. This may enable students to discuss identified problems, collected data, and determine the influence of technology on the understanding of data and conclusions drawn by scientists. Schwab referred to this learning process as "enquiry into enquiry" (Duschl & Hamilton, 1998, p.1060). Schwab (1966) asserted that students should realise that science concepts may continuously change in the light of new scientific discoveries.

During the 1980s, Japan became one of the competitors in the world economy. The Japanese were scientifically and technologically advanced in electronics, automobile manufacturing, and the steel industry. Just like the launch of Sputnik, the Japanese economic advancement also led to disapproval of the US education system since it could not prepare students to enter into science and technological careers (Gardner, 1983). The Japanese economic threat led to another review of the US education system. The National Commission on Excellence in Education in the US compiled a report entitled A *Nation at Risk* (Gardner, 1983). In the report it was claimed that, "our education system has fallen behind and this is reflected in our leadership in commerce, industry, science and technological innovations, which is being taken over by competitors throughout the world" (Gardner, 1983, p. 9). Consequently, there was a great concern from the leaders about the state of maths and science courses in schools throughout the US, claiming that they "lacked rigor, were dogmatically taught, were content oriented, lacked conceptual unity, were out-dated, and had little bearing on what was happening in the scientific disciplines" (Collette & Chiappetta, 1989, pp. 11-12).

In response to the Japanese economic threat, the American Association for the Advancement of Science (AAAS, 1990) published a report, entitled *Science for All Americans: Project 2061* to address the Americans' concerns. Project 2061 outlined science knowledge and skills which students should develop at the end of the K-12 grade. The learning objectives recommended by Project 2061 involved "being familiar with the natural world and respecting its unity, being aware of some of the important ways in which mathematics, technology, and the sciences depend upon one another, understanding some of the key concepts and principles of science, having a capacity for scientific ways of thinking, knowing that science, mathematics, and technology are human enterprises, and knowing what that implies about their strengths and limitations, and being able to use scientific knowledge and ways of thinking for personal and social purposes" (AAAS, 1989, pp. xvii ± xviii).

The science literacy goals of the Project 2061 were documented in the *Science for All Americans report* (SFAA, Rutherford & Ahlgren, 1989) in a section entitled "Habits of the Mind". In addition, inquiry teaching should encompass asking questions about nature, engaging students in group discussions, gathering of data, providing historical perspective, promoting scientific inquiry and discouraging memorisation of scientific concepts. AAAS (1989, p. xii) further advocated the teaching of NOS and SI in high schools by arguing that,

> *"Education in science is more than the transmission of factual information: it must provide students with a knowledge base that enables them to educate themselves about the scientific and technological issues of their times, it must provide students with an understanding of nature of science and its place in society, and it must provide them with an understanding of the methods and processes of scientific inquiry"*.

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Afterwards, *Benchmarks for Scientific Literacy* (AAAS, 1993) structured the inquiry teachings into different grades such as K-2, 3-4, 5-8, and 9-12.

Later the NRC (1996) released the National Science Education Standards (NSES) that used the Project 2061 objectives to transform the US K-12 standards to follow an inquiry approach. According to Abd-El-Khalick (2001), the NSES did not give a definition of inquiry but outlined what students should learn, describing the teaching and assessment approach. Atkin and Black (2003, p.15) stated that the NSES ". . . was intended as an inspiration and guide for state and local education authorities". The NSES further described the application of inquiry in two different contexts. Firstly, inquiry involving students' understanding of scientific inquiry and their ability to participate in inquiry-based activities. Secondly, inquiry involves teachers' understanding of inquiry-based teaching approaches.

Thereafter, the Atlas of Scientific Literacy (AAAS, 2001) elaborated on their interpretation of scientific inquiry of the Benchmarks in a strand map referring to strands and categories, and explained how inquiry should be taught. The first strand of inquiry is evidence and reasoning which has three categories, namely, reasoning, observations and evidence. The second strand is scientific investigation and is divided into four categories, namely, control and condition, trustworthiness of results, maintaining records and types of investigations. The third strand includes the six categories about scientific theories, namely, interpretation of data, possible explanations, amending a theory, trustworthiness of results, precautions and expectancies and clarifications.

As a reflection of this synthesis, since the 1960s, there has been an investigation by researchers about science learning and the teaching practices that could advance the development of scientific knowledge (Newton *et al.*, 1999). Since the 1990's, inquiry-based instruction has become the recommended teaching approach and is believed to promote development of SI skills and the understanding of NOS (Aydeniz, Baksa & Skinner, 2010; Newton *et al.*, 1999).

2.2 Theories supporting inquiry based science education

Five theories about learning were used to furnish the conceptual argument for the current study. They are: the theory of constructivism (2.2.1), the situated learning theory (2.2.2), collaborative learning (2.2.3), conceptual development (2.2.4) and problem-based learning (2.2.5).

2.2.1 The Cognitive Basis of Inquiry Learning: Individual and social constructivism

To start with, constructivist theories of learning were first developed in the cognitive sciences and outlines how individuals create meaning and construct knowledge out of experiences as well as the interpretation of knowledge (Ferguson, 2007; Tobin, 1990). Extensive research from educational psychology (Parsons, Lewis Hinson & Sardo-Brown, 2001; Woolfolk, 2004) describes constructivism as a response to cognitivism/information processing theories. Cognitivism is a theory that aims to explain how the mind works and further indicates that the teacher transmits knowledge which is then received by students. Constructivism differs from cognitivism in that teachers may not be regarded as conveyors of knowledge since "wisdom cannot be told" (Bransford, Franks, Vye & Sherwood, 1989, p. 470).

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Constructivism describes how individuals acquire and interpret knowledge of the natural world (Bodner, Klobuchar & Geelan, 2001; Ferguson, 2007). It outlines how individuals achieve, develop, and utilise the cognitive processes to construct knowledge by themselves (Haney & Lumpe, 2003). Constructivism offers the philosophical basis for multiple types of teaching approaches (Mayer, 2004). Furthermore, constructivism has its own unique concepts of learning and instruction. Constructivism rests on the understanding that "knowledge is not transmitted directly from one knower to another, but it is actively built up by the learner" (Driver, Asako, Leach, Mortimer & Scott, 1994, p.5).

Constructivism is comprised of two main branches: individual and social constructivism (Ferguson, 2007; Palincsar, 1998; Cobern, 1993). Firstly, Piaget's (1965, 1970) cognitive constructivist or personal constructivist theory, focuses on individual's construction of meaning (Driver, 1989; Piaget, 1977, 1970; von Glasersfeld, 1995). Secondly, the social constructivist theory (Vygotsky, 1997, 1978) acknowledges the importance of collaboration in an individual's development of knowledge. Piaget (1965) and Vygotsky (1997) are the two well-known advocates of the constructivist theory.

Piaget, who is regarded as an individual constructivist, believed that learning occurs in the thought processes of a learner and that learners cannot learn anything unless they have reached a certain developmental stage. Piaget (1953) believes that learning may occur through three processes, namely, assimilation, accommodation and disequilibration. Assimilation is the integration of new experiences into the prior knowledge (Roth & Roychoudhury, 1994; von Glasersfeld, 1996; von Glasersfeld, 1981; Yeager 1991). Accommodation is the transformation of the existing knowledge to fit in with the new experiences. Disequilibration is a process of resolving a cognitive conflict between new and old experiences in an individual's thinking. Thus students need to transform old knowledge or experiences to address their own needs and capabilities before accommodating new knowledge into their cognitive structure, or schema (Slavin, 1988).

In contrast, Vygotsky, who is a social constructivist, believed that learning occurs as a result of social interactions amongst students and between students and knowledgeable adults. According to Vygotsky's (1997) theory of social constructivism, learning is not affected by stages of development but by social interactions with the adults. According to the theory of social constructivism (Vygotsky, 1978), effective learning requires that individual knowledge construction should occur through social interaction to negotiate the meaning of new experiences (Arends, 1997; Cobern, 1993; Palincsar, 1998).

Through the guidance of teachers, students may progress to a higher level of understanding (Arends, 1997). Vygotsky argued that effective learning occurs in the zone of proximal development (ZPD). The ZPD is an area between a student's current level and the level which the student can achieve through the assistance of a knowledgeable teacher (Arends, 1997; Bruning *et al.*, 2004). Teachers should use scaffolding to guide students through the ZPD. Scaffolding is a teaching strategy that assists students to perform an action they are unable to do by themselves, but without just giving them the answer (Bruning *et al.*, 2004). Through scaffolding, students are guided to discover knowledge by themselves. In other words, constructivism theory involves a coordination of cognitive constructivist (radical constructivist) (Piaget, 1970) and socio-cultural perspectives (Cobb, 1994; Vygotsky, 1978).

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The current study perceives learning as occurring in an individual as well as a social setting, and has the viewpoint that the facilitation role of a teacher is very important. From a constructivist perspective, the researcher claims that science learning may be viewed as a twofold process. Firstly, it involves a process of individual conceptual change (Gaigher, Rogan & Braun, 2006; Posner, Strike, Hewson & Gertzog, 1982). Secondly, it involves individuals developing new ways of thinking, of understanding the natural world as well as internalising the practices of the scientific community through social interactions amongst students when developing and justifying knowledge claims (Hewson, 1981; Posner *et al.*, 1982).

All constructed knowledge is stored in mental schema. Schema theory considers organised knowledge as a network of abstract mental structures which encompasses an individual's world view and can be used as a tool to explain new experiences in life (Hudgins *et al.*, 2006). The schema or mental model consists of a "framework or plan" (Stein & Trabasso, 1982) of a network of integrated ideas (Anderson & Pearson, 1984; Howard, 1987; Slavin, 1988).

Effective students may in turn reflect on their own conceptions based on available new experiences (Kruckeberg, 2006). The aims of inquiry-based instruction require the active rather than passive participation in investigating scientific questions and the interrogation of their prior knowledge under the supervision of a teacher (Arends, 1997; Brass *et al.*, 2003; Kruckeberg, 2006; Palincsar, 1998; Watson, 2001). The universally accepted five emerging themes (Hassard & Dias, 2005) that need to be incorporated in science teaching include that it should be: effective, realistic, constructivist, address pre–existing knowledge, and encourage cooperative and collaborative work.

Cobern (1993) posited that knowledge is regarded as a meaningful interpretation of individuals' experiences of the natural world. Students acquire an understanding of the new knowledge in relation to their prior knowledge. Constructivism asserts that all new learning occurs in comparison to an individual's previous conceptions (Windschitl, 2003). Constructivist approaches encourage science teachers to have a deeper understanding of their subject content knowledge and that they should promote individual development of contextualised knowledge rather than transmitting decontextualized content knowledge (Prawat, 1993; Treagust, Duit & Fraser, 1996). Teachers' conception of the constructivist strategies may be enhanced if they develop an understanding of the teaching methods that assist in identifying students' prior knowledge at the beginning of each lesson.

Students learn differently due to differences in prior knowledge and different ways of interpreting new experiences. It is also acknowledged that the constructivist perspective does not suggest that students may learn through direct transmission of knowledge since knowledge to be learnt should not be separated from the learner (Cobern, 1993; Driver *et al.*, 1994; Osborne & Freyberg, 1985; Palincsar, 1998; Watson, 2001). Novak, Mintzes, and Wandersee (2000, p. 8) asserted that, "teachers must be able to plan their own curriculum, they must be able to sequence topics in such a way that new knowledge is more easily built on previous learning, and they must master a set of strategies that aim at helping learners restructure their scientific understandings".

However, it should be emphasised in the current study, that, "what we call constructivism in science education has little to do with philosophical constructivism" (Gil-Perez *et al.*, 2002, p.559). In addition, constructivism has been used not only as a theory of scientific knowledge but it is also considered as a theory of learning embedded in the work of Socrates (Matthews

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1997, 2002). Research has further suggested that the construction of scientific knowledge by students engaged in GI investigations should not be equated with the generation of scientific knowledge by scientists when conducting experiments (Nola, 1997). According to Chi, Feltovich and Glaser, (1979) and Chi, Bassok, Lewis, Reimann and Glaser, (1989), experts' (scientists') schemata differ from novices' (students') schemata. Scientists' schemata are comprised of procedural knowledge with clear abstracted solution methods of a problem. In other words, scientists use science principles providing the answers to problems. Conversely, students' schemata are comprised more of declarative knowledge that focus on the physical patterns of a problem, which cannot formulate abstract solutions. Samarapungavan (1992) emphasised that scientific knowledge constructed by scientists has explanatory power since it is supported by a variety of explanations, with empirical evidence and logical reliability.

The constructivist theory of learning further explains the persistence of misconceptions in science teaching. Many science students bring to class their alternative views and beliefs about science concepts that are significantly different from the scientifically accepted knowledge (Norvilitis *et al.*, 2002; White, 1993). The students' alternative views cannot be easily transformed even when they are taught the accepted concepts. This could be explained by considering that students' new learning experiences lacked scaffolding (Pajares, 1992).

New experiences are not integrated into the existing cognitive schema unless it can be interpreted in the light of existing prior knowledge (Bruning *et al.*, 2004; Pope & Gilbert 1983). Prior knowledge has been extensively researched in science teaching and is believed to be a critical determinant of learning (Johnson & Lawson, 1998**.** From misconception research, it has been established that students develop new concepts based on previous knowledge (Novak, 1990). Additionally, previous knowledge does not affect conceptual learning only but it also impedes a student's insight and ability to focus.

Indeed, students should be actively involved in the interpretation of and internalisation of new experiences for meaningful learning to occur (Arends, 1997; Cobern, 1993; Kruckeberg, 2006; Palincsar, 1998; Watson, 2001). When students are unable to understand the abstract nature of science, they resort to rote learning style and believe that they have no talent for science (Driver, Leach, Millar, & Scott, 1996).

2.2.2 Situated learning theory

Lave (1993, p.7) describes the difference between the situated learning theory and the cognitive theories of learning by positing that,

> *"Traditionally, learning researchers have studied learning as if it were a process contained in the mind of the learner and have ignored the lived-in world.… Theories of situated activity do not separate action, thought, feeling, and value and their collective, cultural-historical forms of located, interested, conflictual, meaningful activity. Traditional cognitive theory is 'distanced from experience' and divides the learning mind from the world".*

The fundamental feature of situated learning theory is that knowledge cannot be separated from the learner having the knowledge, nor reasoning from an action (Lave, 1988). In addition, Lave (1996) claimed that learning should be understood as a process that may or may not be caused by teaching. Knowledge, according to the situated learning theory is believed to be "situated". This entails that knowledge is a result of the action, culture and setting within which the knowledge is generated and applied (Lave *et al.*, 1991). Learning is a

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contextually bound activity, the context does not only influence the learning process but also affect how learning occurs.

The second critical aspect of situated learning theory is a “community of practice”. A community of practice may be described as a team of individuals sharing common practice in pursuit of similar goals. According to Wenger (1998) there are two interrelated but different perspectives associated with community of practice: the practice perspective and identity. The practice perspective describes how one community differs from other communities in terms of their traditions. The identity perspective describes how individuals relate to the community of practice.

From the social practice theory’s perspective Barton, Kang, Tan, O’Neill, Bautista-Guerra, and Brecklin (2013) revealed that studies on identity formation are very complex since identities are always changing and are socially negotiated. These authors used identity work instead of identity formation. According to Barton *et al.* (2013), identity work refers to the activities individuals perform and the associations they develop at any time irrespective of the influence of the social, cultural, and historical principles of the environment in which they are found. Identity work enables an individual to develop numerous identities over time irrespective of the context they are in.

According to the social practice theory, identities indicate one’s changing living environment. When individuals shift from one context to another, they are faced with different people, cultural norms and values (Holland, Lachicotte, Skinner & Cain, 2001). Individuals may continuously transform their identities to suit the community needs and the contexts in which they live. Holland *et al.* (2009) argued that individuals may author new identities in accordance with the social and cultural values as well as economic conditions of the new communities of practice they are part of. Put differently, who an individual is, in the past, present and possibly in future is dependent upon the actions one undertakes while transforming old identity and adapting to new cultural activities of the new community of practice (Holland *et al.*, 2009).

When individuals become members of other communities of practice, they rely on their previous experience gained elsewhere to develop practices that may or may not fit in with the new community (Holland *et al.*, 2009). The processes of identity work are not easy to understand, since acceptance of an individual in a new community is a product of social influences in that context (Nasir, 2011) which reflect both the cultural values and established differences (Eisenhart & Finkel, 1998; Holland *et al.*, 2001). Consequently, identity is a useful tool for recognising students’ learning. Identities are formed through practise which includes knowledge, abilities and reasoning skills that characterise the relevant field of study.

“Legitimate peripheral participation” is the third key feature of the situated learning theory. Through “legitimate peripheral participation” newcomers in the community of practice improve their skills and ultimately become accepted in the community (Lave *et al.*, 1991). Lave *et al.’s* (1991, p.95) established model of learning indicates that participation is described as a tool for learning, “of both absorbing and being absorbed in the ‘culture of practice’ ”. In this learning approach novices firstly partake in the processes not critical to the community of practice and thereafter proceed to more challenging and fundamental processes. During authentic peripheral participation, novices progressively do not only acquire their knowledge in the community of practice but they also enhance their understanding of the existing norms and values. According to Lave *et al.* (1991):

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> *"As an aspect of social practice, learning involves the whole person, it implies not only a relation to specific activities, but a relation to social communities – it implies becoming a full participant, a member, a kind of person. ... To ignore this aspect of learning is to overlook the fact that learning involves the construction of identities" (Lave* et al.*, 1991, p. 53).*

According to Lave *et al.* (1991, p.95) novices may acclimatize and begin to understand various activities of the community of practice and realising "who is involved, what they do, what everyday life is like, how masters talk, walk, work, and generally conduct their lives, how people who are not part of the community of practice interact with it, what other learners are doing., and what learners need to learn to become full practitioners".

Wenger, 1998, summarises the process of learning from the viewpoint of the community of practice as:

> *"Evolving forms of mutual engagement: discovering how to engage, what helps and what hinders, developing mutual relationships, defining identities, establishing who is who, who is good at what, who knows what, who is easy or hard to get along with.*
>
> *Understanding and tuning their enterprise: aligning their engagement with it, and learning to become and hold each other accountable to it, struggling to define the enterprise and reconciling conflicting interpretations of what the enterprise is about.*
>
> *Developing their repertoires, styles, and discourses: renegotiating the meaning of various elements, producing and adopting tools, artifacts, representations, recording and recalling events, inventing new terms and redefining or abandoning old ones, telling and retelling stories, creating and breaking routines". (Wenger, 1998, p. 95).*

Lave (1992, p.3) posited that learning is understood as "a process of coming to be, of forging identities in activity in the world". According to Danielsson (2009), learning is not only understood as the development of content knowledge but also as the creation of an identity. For instance, when an individual learns physics, that individual does not only learn the subject matter but also understands how a physicist works in the culture of the physics community. In addition, how an individual understands physics gives rise to how an individual views himself/herself as being and developing in a given situation. Learning science comprises understanding a variety of processes that form part of the social and cultural practices of a science discipline. Mastering the system of activities in a community of practice may enable one to be established and identified as an agent of change by other members (Holland *et al.*, 2001).

Cognitive apprenticeship as one form of inquiry involves cooperative learning (Collins, Brown & Newman, 1989; Collins, Hawkins & Carver, 1991; Giere, 1998, 2002, 2004; Rogoff & Lave, 1984). According to this approach learning science entails being apprenticed into the conversational and reasoning practices of a community of scientists (Edwards & Mercer, 1987; Lemke, 1990). The fundamental aspects of cognitive apprenticeship include: modelling, teaching, performing of activities, as well as self-evaluation. Cognitive apprenticeship could be beneficial in that students should be taught how to think like scientists by being engaged in scientific practices. It is hoped that when students are exposed

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to scientific practices, they may acquire science content and also internalise the scientific processes. Subsequently, the obligation of science teachers may be to assist learners to construct knowledge in the approaches that are related to their life experiences.

Roth (1995) claims that physics learning should be understood as the process of becoming familiar with the practices of generating knowledge in the physics community. Learning occurs through enculturation, which is believed to be the changing involvement in a community of practice (Bereiter *et al.*, 1993; Lave *et al.*, 1991; Reiner, 1995). Enculturation involves becoming familiar with theoretical conventions and the acquisition of communication skills and collaboration skills (Brown, Metz, & Campione, 1996; Driver *et al.*, 1994; Rogoff, 1995). Put differently, enculturation means understanding the thought processes involved in the generation and justification of physics knowledge. "Learning science involves young people entering into a different way of thinking about and explaining the natural world, becoming socialised to a greater or lesser extent into the practices of the scientific community with its particular purposes, ways of seeing, and ways of supporting its knowledge claims" (Driver *et al.*, 1994, p. 8).

Scientific models and concepts which were developed, confirmed and accepted by the scientific community cannot be discovered by individuals by themselves (Driver *et al.*, 1994). Learning science thus implies being introduced to the concepts and methods of the science community and understanding them. Students may appropriate physics tools for performing activities, starting from the meanings of physics concepts to different scientific methods and the epistemologies of science knowledge by being introduced in the culture of a physics community (Brown *et al.*, 1996; Rogoff, 1995).

Furthermore, participation in the community of practice requires an individual to appropriate the language used in the community to share ideas with other members. Students may be familiarised with the vernacular of the physics community by capable adults and need to understand the symbolic forms of others as well as being able to translate these forms into language. Hence the responsibility of a science teacher is to assist students in understanding different ways of generating and validating science knowledge, instead of transmitting ready-made knowledge about the natural world. Thus, learning is believed to indicate identity transformation.

2.2.3 Collaborative/cooperative learning

Learning by inquiry can also be described as cooperative learning. From a constructivist perspective, group work and collaboration among students stimulate the negotiation of meanings and reaching certain agreements and provide mechanisms in the disequilibration of inconsistency and disagreements (Wheatley, 1991). In particular, inquiry-based learning is embedded in social constructivism. Vygotsky regarded social interaction as the foundation upon which new knowledge could be constructed (Arends, 1997; Cobern, 1993; Palincsar, 1998). Social constructivism theory asserts that effective learning occurs when teachers and learners work collaboratively to generate knowledge by conducting investigations, and finding resolutions to the investigative questions (Arends, 1997; Bruning *et al.*, 2004; Kruckeberg, 2006; Watson, 2001).

According to Arends (1997), classroom instruction goal structures can be classified into three types: competitive, individualistic and cooperative. Competitive goals are goals in which students are rewarded in relation to the other students, like in class and semester tests (Arends, 1997). Very few students may succeed in a classroom learning environment that

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encourages a competitive goal structure, as competition is encouraged amongst students (Johnson, Johnson & Holubec, 2002; Ramsier, 2001). In this kind of learning environment students are encouraged not to support each other but to celebrate if their colleagues are failing (Johnson *et al.,* 2002; Arends, 1997). In a competitive environment, students rarely assist each other in the fear that the student they are assisting may do better than themselves (Johnson *et al.,* 2002; Ramsier, 2001).

The learning environment that promotes individualistic goal structure rewards students individually but not in comparison with the others (Arends, 1997). In individualistic learning, students may assist each other but they are not encouraged to do that (Arends, 1997; Johnson *et al.,* 2002). A cooperative goal structure encourages group work and the reward students receive, is based on the success of the entire team (Arends, 1997). In cooperative learning environment students assist one another and rejoice in the success of all group members (Johnson *et al.,* 2002). Cooperative learning encourages supportive relationships among students which also increase students' self-confidence (Johnson *et al.,* 2002). Even though the three goal structures could be applied in different teaching approaches, cooperative learning creates a learning environment conducive for inquiry-based learning. In a collaborative learning environment students collaboratively work together towards similar learning objectives (Johnson *et al.,* 1998; Johnson *et al.,* 2002). However, it should be noted that cooperative learning is more challenging to manage than the other forms of instruction since students are working in small groups when addressing a given task (Johnson *et al.,* 2002). Nonetheless, cooperative learning promotes collective team work among students (Arends, 1997; Pressley *et al.,* 1995; Ramsier, 2001).

In addition to social constructivism, cooperative goal structure enhances students' interactions and increases team-work better than individualistic and competitive goal structures (Arends, 1997; Johnson *et al.,* 2002; Pressley & Woloshyn, 1995). Moreover, collaborative team efforts in cooperative learning increase students' productivity and academic performance (Arends, 1997; Johnson *et al.,* 2002; Pressley *et al.,* 1995). Furthermore, a cooperative learning environment improves students' critical thinking skills and the conceptualisation of everyday science (Arends, 1997; Norvilitis *et al.,* 2002).

Disagreements often occur between students exchanging ideas in cooperative learning and cause cognitive conflict (Johnson *et al.,* 1998). This is not a disadvantage to students but it is good for learning. This cognitive dissonance can be resolved by accommodating different views of other group members thus deepening students' intellectual development (Johnson *et al.,* 1998). The collaboration amongst students provides an opportunity for the exchange of views and reaching a negotiated agreement which is an essential tool for resolving cognitive conflict (Wheatley, 1991). The interactions amongst students and different groups in a laboratory environment promote construction of science concepts and attaining intended learning outcomes.

According to research, cooperative learning strategies create a better link between laboratory and classroom activities and promote better academic achievement (Johnson *et al.,* 1985). Collaborative planning and discussions of the results provide an environment in which implicit ideas become explicit. Usually communication and reflection are promoted through preparation and discussion of the laboratory reports. Preparation of a report allows students to revisit and review their opinions, propositions, ideas and theories. Dialogue is a social constructivist activity between students which provides a chance for students to learn from

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their colleagues' ideas and develop better understanding and solutions (Lazarowitz *et al.*, 1994). Collaborative methods provide students with opportunities to propose clarifications, understandings and solutions that will address problems (Brown & Palincsar, 1989).

Research indicates that students in a collaborative learning environment develop problem solving skills, perform better in conceptual tests than their colleagues in a traditional learning environment, have positive attitudes towards science and are satisfied with the interactive environment (Beichner, Saul, Allain, Deardorff & Abbott, 2000). Syh-Jong (2007) investigated students' construction of science knowledge through talking and writing in a collaborative environment. The results from this study demonstrated that writing and talking in a collaborative environment required students not only to defend their science conceptions but also to incorporate other students' ideas in clarifying their understanding.

In another study, Peer Instruction (PI) was used for a period of more than ten years in the introductory Physics at Harvard University (Crouch, Watkins, Fagen & Mazur, 2007). PI is a teaching approach of involving all students in the learning process using structured questions. The results found in this study demonstrated that PI promoted students' conceptual reasoning and quantitative problem solving skills. Similarly, Qin and Johnson (1995) showed that students from a collaborative group outperformed students from a traditional group on four types of problem solving.

2.2.4 Conceptual development of individual scientific knowledge

Conceptual development of science knowledge is the "understanding of the ideas in science which are based on facts, laws and principles and which are sometimes referred to as 'substantive' or 'declarative' concepts" (Gott & Duggan, 1995, p. 26). Students' views which are different from those of the physics discipline are also referred to as misconceptions, alternative conceptions or alternative frameworks. Hammer (1996, p. 1319) contended that, "…it has become standard to accept that students come to courses with conceptions that differ from scientists' and must be addressed". The investigation on students' perceptions of scientific concepts resulted in the formulation of a conceptual change model of learning (e.g. Posner *et al.*, 1982).

Empirical evidence from psychological studies and science teaching has dismissed the belief that learners in class should be regarded as blank slates that need to be loaded with information. Rather learners come to class with alternative conceptions that hinder their learning process (Carey, 2000; Keil, 2011; Vosniadou, 1994). Consequently, science teachers are faced with two responsibilities: assisting learners to learn the correct scientific knowledge and guiding students to change their misconceptions. Research on conceptual change has described the shift from misconceptions to accepted scientific knowledge differently.

Several researchers have described the purpose of categorical knowledge in conceptual development (Carey, 2009; Smith, 2007). According to these researchers, conceptual change was described as conceptual combinations in which old category knowledge boundaries are collapsed and new category knowledge boundaries are established. Some researchers have outlined the role of ontological hierarchies in knowledge transformation (Chi, Slotta & de Leeuw, 1994; Thagard, 1992). These researchers described conceptual change as the rearrangement of science concepts in different levels of ontological hierarchy. Others have considered the purpose of contributing prospects in conceptual development, describing

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conceptual change as a modification of the central assumptions of an underlying theory or model (Vosniadou, 1994; Wellman & Gelman, 1992).

For instance, Driver, Leach, Millar, and Scott, 1996, described how conceptual change occurs when children learn science from a constructivist perspective. Extensive literature about children's mental schemes (Getner & Stevens, 1983; Osborne & Freyberg, 1985) demonstrates that children learn science by drawing information from their knowledge schemes. What students may learn from the science activities is not only determined by how activities were designed but also by the knowledge schemes students bring to class (Driver & Bell, 1986). Subsequently, learning is viewed as the interaction between students' mental schemes and the new experiences gathered during the learning process. When new experiences do not integrate well with prior knowledge, little change may occur in student's mental schemes. Conversely, when new experiences fit well with the pre-existing knowledge, old knowledge schemes may either be changed or adapted to a new context. The process of applying knowledge in new situations and tasks requires active engagement by students in accessing knowledge from their mental schemes and eventually transforming it. Consequently, learning science is also understood as advanced development and reorganisation of students' knowledge schemes.

During the 1970s, many educational researchers have conducted their research studies in conceptual change. Different theorists further described what conceptual change is and how it could be attained. The simplest explanation of conceptual change, according to Hewson (1992), is the transformation of student's prior conceptions or misconceptions to be in accordance with the scientifically accepted views. Hewson (1992) further describes three different forms of conceptual change. Firstly, students may replace their pre-existing knowledge with the accepted scientific concepts. Secondly, students' prior knowledge may be composed of both alternative views and acceptable concepts. As a result, addressing the alternative views is also regarded as a conceptual change. Thirdly, students have a limited experience that led to the development of their alternative views, thus the development of new concepts in students' cognitive organisation is regarded as conceptual change.

On the other hand, Posner *et al.* (1982, p.211) describe conceptual development as the "process by which people's central, organizing concepts change from one set of concepts to another set, incompatible with the first". According to the orthodox conceptual change model (CCM) (Hewson & Hewson, 1984; Posner *et al.*, 1982; Strike & Posner, 1985), there are two fundamental factors that are essential to learning about science content as conceptual change, namely status and conceptual ecology. Pre-existing knowledge (of low status) in students' schema can be replaced with new information (of high status) provided the new knowledge satisfies the requirements of dissatisfaction with current understanding, credibility, understandability and utility (Hewson & Thorley, 1989). Evaluation of the status of knowledge is done considering students' contemporary conceptual understanding comprised of epistemological commitments, world opinions about the understanding and abstract science views that are not linked to any researched findings (Posner *et al.*, 1982).

According to Posner *et al.* (1982) the subject content knowledge may follow the conceptual change process provided four conditions are met. Firstly, there is dissatisfaction in which students should be dissatisfied with their current state of cognitive structure and feel that it should be changed. Secondly, intelligibility refers to a state when new concepts are presented to students. Their meanings should be understood and relate to other concepts in their prior knowledge for conceptual change to take place. Thirdly, plausibility refers to a state where the new presented knowledge should be realistic, believable, coherent and integrate with

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students' prior knowledge for conceptual change to occur. Lastly, fruitfulness refers to the utilisation of the new presented knowledge to solve immediate problems as well as providing students with abilities to initiate new research and discoveries.

According to the work of Kuhn, Amsel, and O'Loughlin (1988), the growth in students' conceptual understanding is perceived through the lens of describing a learning process in which learners' views are transformed as a result of evaluating new evidence and interpreting evidence in terms of existing theory Conceptual change models are used as tools to reduce the gap between students' and scientists' understanding of science knowledge (Hewson, 1981; Posner *et al.*, 1982). Several models of conceptual change are underpinned by Piaget's theory of individual learning and social constructivism (Gega, 1994; Hewson & Hewson, 1983; Hynd *et al.*, 1994; Posner *et al.*, 1982; Stofflett, 1994). Conceptual change models suggest creating disequilibration or cognitive conflict in students' minds with their alternative views and thereafter strengthening the status of the accepted science concepts. In addition, social constructivism insists that peer/social interaction and group discussions also lead to conceptual change (Brophy, 1986; Uzuntiryaki, 2003; Vygotsky, 1978). According to the social constructivist view of learning, knowledge is socially constructed (Duit, 2002). Moreover, group discussions may generate intrinsic motivation which plays an essential role in knowledge construction (Pintrich, Marx, & Boyle, 1993).

Since the 1990's, science teaching has widely used cognitive conflict based lessons. It was concluded from many studies that cognitive conflict instruction enhances conceptual development (Druyan, 1997; Kim, Choi, & Kwon, 2002; Stern, 2002; Kwon, 1997; Lee *et al.*, 2003; Niaz, 1995; Thorley & Treagust, 1987). Lee *et al.* (2003) and Kwon (1997) advocated the use of cognitive conflict based instruction to promote conceptual change. Kwon and Lee (1999) found that students that experienced higher levels of conflict indicated very high rate of conceptual change from wrong to correct conceptions, while those that had low level of conflict illustrated minimal conceptual development. Ting and Chong (2003) established that cognitive conflict instruction promotes conceptual development. Zohar and Aharon-Kravetsky (2005) established that the cognitive conflict teaching method enhanced the performance of academically high achieving students. In contrast, certain researchers do not believe that cognitive conflict teaching could cause a conceptual change (Dekkers & Thijs, 1998; Dreyfus, Jungwirth & Eliovitch, 1990; Elizabeth & Galloway, 1996; Hewson, Beeth, & Thorley, 1998; Limon, 2001). Furthermore, research has shown that some students resisted integrating new experiences in their mental schemas since experiences conflicted with their misconceptions (Bergquist & Heikkinen, 1990).

Resnick (1989) described conceptual understanding as the interrelationships among facts, concepts and principles in a content area. Conversely, attaining conceptual change is also believed to include understanding new ideas and accepting them (Chinn & Samarapungavan, 2001, 2009; Ohlsson, 2009). Donovan, Bransford and Pellegrino (1999) indicated that cognitive science research has shown that conceptual understanding enables students to solve scientific, technological and environmental problems in any contextual situation. Kozma *et al.* (1996) highlighted that students do not grasp core concepts in a discipline without assistance from the experts. Instead they argued that extensive guidance is needed for novice students to develop deep–thought processing and conceptual understanding. The teachers' guidance serves as scaffold to assist students to transit from their current state of understanding to the one that is closer to expert's understanding.

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Students have developed strong conceptions about how the world operates over many years of experience in their life (Posner *et al.*, 1982). Consequently, a meaningful learning experience would require a teaching approach that may both transform previously held perceptions and encourage assimilation of scientifically sound conceptions (Roth & Lucas, 1997). Effective physics teaching should promote the type of learning that leads students to conceptual understanding (Dykstra *et al.*, 1992).

As a result, physics instruction should focus on creating a conducive interactive learning environment to facilitate students' learning of science content (Dykstra *et al.*, 1992). Students may construct appropriate scientific conceptions if they participate in learning situations that encourage them to interrogate their own conceptions (Kalman, Morris, Cottin & Gordon, 1999). Students should be confronted with discrepant events that oppose their concepts and epistemological beliefs (Hammer, 1995), and cause a cognitive dissonance that encourages students to review and modify their understanding (Piaget, 1985). According to Tao and Gunstone (2003) a discrepant event may be a phenomenon which may provoke students to state their predictions. Duit *et al.* (2003, p. 673) asserted that,

> *"The classical conceptual change approach involved the teacher making students' alternative frameworks explicit prior to designing a teaching approach consisting of ideas that do not fit the students' existing ideas and thereby promoting dissatisfaction. A new framework is then introduced based on formal science that will explain the anomaly".*

2.2.5 Problem-based Learning

When students are conducting inquiry laboratory practical activities they are also engaged in problem-based learning (PBL) similar to discovery-learning where students are given a real-life problem to solve. In small groups, students may formulate a research problem, figure out a way of solving a problem, collect relevant data, evaluate data and formulate alternative solutions and selecting the best solution to a given problem. According to (Barrows, 2000), PBL refers to inquiry-based learning in which experiential learning is centred on the investigation, explanation and solving of real-life problems. Irrespective of the different forms of PBL that changed over the time, Barrows (1996) identified six core characteristics of PBL. Firstly, PBL is student-centred. Secondly, collaborative learning occurs in small groups under the supervision of a teacher. Thirdly, a teacher always acts as a facilitator or a guider of a learning process. Fourthly, real-life problems are integrated with the content to be learnt by students. Fifthly, real-life problems prepare students to develop problem-solving skills and to achieve the intended knowledge. Lastly, new knowledge is acquired through self-directed learning.

2.3 Nature of science

Science education researchers describe the NOS construct as the epistemology of science. NOS focuses on the philosophical assumptions that underpin science knowledge (Smith & Wenk, 2006) such as, values, improvement, theoretical developments, distinctive features of science knowledge and how agreements are reached in science communities (Lederman 1992; Tsai, 2007). Lederman *et al.* (2004) described NOS as a set of beliefs and conventions essential to the generation of science knowledge. There is considerable research that indicates the importance of learning about NOS. For instance, Carey and Smith (1993, p. 235) state that development of learners' NOS understanding may enhance, "lifelong learning, and a

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valuing of the kind of knowledge that is acquired through a process of careful experimentation and argument, as well as a critical attitude toward the pronouncements of experts". Similar views were also expressed by other researchers (e.g. Akerson, Morrison & McDuffie, 2006; Chin, 2005; Clough, 2011; Eflin, Glennan & Reisch, 1999; McComas, 2000).

NOS is a multifaceted construct and there is no agreement amongst science educators regarding its precise definition. The current study is informed by Lederman's (1992, p.331) description which illustrates NOS as the "epistemology of science, science as way of knowing, or the values and beliefs inherent to the development of scientific knowledge". According to the NRC, "Epistemic knowledge is knowledge of the constructs and values that are intrinsic to science. Students need to understand what is meant, for example, by an observation, a hypothesis, an inference, a model, a theory, or a claim and be able to distinguish among them" (2012, p. 79). This citation outlines a sequence of ideas and activities critical to understanding NOS and supplements the practices embedded in scientific explorations, experiments and field studies.

The technical differences in the definition of NOS which have been and are still occurring amongst the science educators, philosophers and historians of science are irrelevant to high school learners (Abd-El-Khalick, Bell, & Lederman, 2000). Some scholars indicate that the issues under discussion amongst these three groups "are far too abstract for K – 12 students to understand and far too esoteric to be of immediate consequence to their daily lives" (Lederman & Abd-El-Khalick, 1998, p. 3). In addition, a level of agreement has been reached on features of NOS that can be understood by high school learners (Abd-El-Khalick *et al.*, 1998; Lederman, 1992; Meichtry, 1993). These NOS features include realising that science knowledge is: tentative, has to be supported by empirical evidence, subjective, to a certain extent rely on human imagination and creativity, and influenced by social and cultural values. Further features are the distinctions between observations and inferences and how scientific theories and laws are related (Khishfe & Lederman, 2006). Schwartz *et al.* (2002, p. 207) argue that, "there is not a single 'nature of science' that fully describes all scientific knowledge and enterprises – various representations of NOS have been affirmed by historians, philosophers of science, science educators, and others." Chalmers (1999, p.247) further argued that, "there is no general account of science and scientific method to be had that applies to all sciences at all historical stages in their development". NOS aspects as described by Khishfe *et al.* (2006) should be understood by first year physics students and are therefore relevant to the literature review for the current study. These NOS aspects are therefore discussed in some detail below.

2.3.1 Empirical nature of science knowledge

Science relies upon empirical evidence acquired through observations of the natural world, and is therefore different from other disciplines like philosophy and religion. The empirical aspect of NOS refers to how science knowledge is developed, justified and incorporated by the science community based on observations of the natural world. Abd-El-Khalick (2005, p.17) argues that science knowledge is developed using "critical, negotiated, and collaborative inquiries that are propelled by scientists' imaginations and bound only by their observations of the natural world". Lederman *et al.* (2004) argue that understanding scientific knowledge such as theories and laws are consequent to scientists' observations of the natural world. Additionally, science knowledge requires justifications of claims by empirical evidence that can also be substantiated via scientific inquiry and logical reasoning (AAAS, 1993; Abd-El-Khalick *et al.*, 2000). Evidence that supports scientific knowledge is clarified

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using scientists' insight in the interpretations of the natural world, complex instrumentation during data analysis as well as by variety of theoretical frameworks (Lederman *et al.*, 2004). Thus, science differs from disciplines such as philosophy and art, because science knowledge is embedded on experiential evidence explained by human interpretation (Lederman, 1992).

2.3.2 Differences between observations and inferences

Science knowledge is entrenched in both observations and inferences. Lederman *et al.* (2004) argued that students should be taught to differentiate between observations and inferences. Observations are assertions that describe natural phenomena acquired through the use of our senses. Inferences are the conclusions drawn from these observations (Liang, Chen, Chen, Chen, Kaya, Adams, Macklin & Ebenezer, 2009). A natural occurrence is inferential if it "can only be accessed or measured through its manifestations or effects" (Lederman *et al.*, 2004, p. 37). So the observation is explained using existing theory, therefore the inference is theory laden.

2.3.3 Differences between scientific theories and laws

Scientific theories are general explanations of the mechanisms behind natural phenomena. These mechanisms are generally not directly observable but they describe the connection between observations of several natural phenomena, some of which may be abstract and not directly tested (Lederman *et al.*, 2002; McComas, 1998). For instance, the Kinetic Molecular Theory provides a description that matter is comprised of small particles called atoms. These atoms are arranged in different patterns in three different states of matter, that is, solid, liquid and gas. This theory further explains the rates of diffusion, physical changes associated with the changes in kinetic energy and the transfer of energy (Abd-El-Khalick, Lederman, Bell & Schwartz, 2001).

In contrast, laws are "descriptive statements of relationships among observable phenomena" (Lederman *et al.*, 2002, p.500). Consequently, scientific theories and laws are diverse kinds of information and that theories don't transform into laws over time (Abd-El-Khalick *et al.*, 2001). Many students think that theories may eventually change into laws. This is incorrect, theories explain laws. In other words, scientific theories provide support for the descriptions of phenomena that are not directly seen, theories are uncertain and encounter transformation and amendment in the light of new scientific knowledge (Wong & Hodson, 2009).

Lederman *et al.* (2004) explained the distinction between theory and law using Kinetic molecular theory and Boyle's law as examples. Boyle's law portrays the visible relation between the volume of a gas and pressure at a fixed temperature. The Kinetic molecular theory broadly describes Boyle's law by explaining the behaviour of gas particles in a certain way. Theories and laws do not constitute the same kind of scientific knowledge, but students should know that theories do not change into laws (Lederman *et al.*, 2004). However, many teachers and students think that scientific laws are certain and proven whereas theories are unproven ideas. They also hold the misconception that there is a hierarchical relation between theories and laws or that theories may later change and become laws (Aikenhead & Ryan, 1992; McComas, 1998).

2.3.4 Human imagination and creativity

Doing science includes using creativity and imagination in all stages of investigations to formulate ideas, invent models to develop theories and to find strategies to examine different scientific views (AAAS, 1990; NSTA, 2000). Most teachers and students believe that

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imagination and creativity are only used in the design of practical activities and problem-solving but not in the generation of scientific knowledge (Aikenhead *et al.*, 1992; Akerson *et al.*, 2000).

2.3.5 Social and cultural embeddedness

Although science knowledge is considered to be common and the same for all people all over the world, science is a human undertaking which is affected by the social and cultural background of the investigators (Abd-El-Khalick *et al.*, 2000; Lederman *et al.*, 2002; Lederman, 1992). Lederman *et al.* (2004) contended that students need to understand that science knowledge influences and is influenced by cultural values and the socio-cultural environment in which it was developed. Examples include religious conviction, legislations and authority structures.

For instance, Galileo Galilei was under house arrest in Rome until his death in 1642 for supporting the Copernican idea that the sun rather than earth was in the centre of our planet system. History demonstrates the political and religious influences on science knowledge and the contradiction between science and the prevailing religious beliefs during Galileo's time. A naïve view of the cultural influence is the view that science cannot be affected by cultural or societal views. For instance, many teachers and students consider science as a discovery of "the universal truth" not influenced by cultural and societal values (Bencze, Di Giuseppe, Hodson, Pedretti, Serebrin & Decoito, 2003; McComas, 1998).

2.3.6 Subjective nature

Science is a human endeavour, and is entirely reliant on scientists' interpretations of observations of natural phenomena (Liang *et al.*, 2009). Interpretation of a natural world phenomenon is attained through explanations and conclusions in agreement with existing scientific theories and hence is theory-laden (AAAS, 1993; Abd-El-Khalick *et al.*, 2000). This means that researchers are influenced by their pre-existing experiences of science knowledge which could result in many justifiable conclusions (Lederman *et al.*, 2004; Lederman *et al.*, 2002). In support of this assertion, Chalmers (1999, p.7) writes "what observers see, the subjective experiences that they undergo, when viewing an object or scene is not determined solely by the images on their retinas but depends also on the experience, knowledge and expectations of the observer." One of the misunderstandings believed by many teachers and students is that different researchers would always arrive at the same objective observations and inferences of a given phenomenon (Chen, 2006; McComas, 1998).

2.3.7 Diverse scientific methods

Students in schools are usually taught that there is a single universal scientific method comprised of a step-by-step procedure that is used by scientists in their research (e.g. Anderson, 2007; Bradley, 2005; Lunetta, Hofstein & Clough, 2007). Researchers use a combination of different scientific methods depending on their prior experiences, imagination and creativity and current paradigms in their fields of research (Kuhn, 1970). Nevertheless, many teachers and students think that conducting experiments is a single way of generating scientific knowledge (McComas, 1998) and those scientists follow the step-by-step cookbook method to arrive at legitimate and reliable results (Ryan & Aikenhead, 1992; Tsai, 1998a).

The different aspects of NOS listed above may seem disconnected at first. However, closer consideration reveals they all fall under the umbrella of the empirical and subjective nature of

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science: Science comprises of not only observations of natural phenomena but also the human interpretation thereof. Driver *et al.* (1994, p.5) posited that "… scientific knowledge is symbolic in nature and socially negotiated. The objects are not the phenomena of nature but constructs that are advanced by the scientific community to interpret nature".

2.3.8 Tentativeness

Science knowledge is durable but tentative, that is, it may change in the light of technological advancement and understandings (AAAS, 1990; Lederman *et al.*, 2002; National Science Teachers Association (NSTA), 2000). History of science indicates that science knowledge could be changed through the evolution or revolution of scientific ideas (Popper, 1998., Kuhn, 1970). Popper (1963) argued that theories, laws and hypotheses can never be confirmed, regardless of the existing empirical evidence supporting it. Kuhn (1962) asserted that scientific revolutions may be driven by the dissatisfaction which occur when existing theories can no longer provide satisfactory explanations for the current scientific developments. This according to Kuhn may encourage new scientific thinking and new research that may give birth to new ideas. Wong *et al.* (2009) established that researchers believe that current understanding of a natural phenomenon may change when new information is discovered through use of advanced technologies. Science knowledge is therefore not definite because it may continuously be transformed and elaborated upon as new information of natural phenomena is realised.

Many teachers and students tend to regard scientific knowledge or theories as unchangeable. They believe that science investigations and practical activities are meant to discover "facts and truth".

2.3.9 Different approaches in the teaching of NOS

Numerous investigations have demonstrated that many students at various levels of education (Dawkins & Dickerson, 2003; Griffiths & Barman, 1992; Kang, Scharman & Noh 2005), teachers and prospective teachers (Akerson & Donnelly 2008; Chin, 2005; Erdoğan 2004; İrez, 2006) have uninformed understandings of different aspects of NOS. Various approaches were established to improve instructors' understanding of NOS with different degrees of achievement.

On the one hand, the implicit teaching approach does not regard understanding of NOS aspects as a cognitive outcome, but assumes that learners would automatically grasp NOS by participating in inquiry activities (Abd-El-Khalick *et al.*, 2000; Akerson & Abd-El-Khalick, 2003). Implicit inquiry-based instruction incorporates implied ideas about NOS entrenched within scientific investigations (Schwartz *et al.*, 2004). Additionally, in implicit approaches, no consideration is given to addressing aspects of NOS but it is assumed that students may naturally acquire NOS understanding by participating in the inquiry activities. Nonetheless, science education research including quasi-experimental, pre-test / post-test comparison group design studies (e.g. Abd-El-Khalick & Akerson, 2004; Khishfe & Abd-El-Khalick, 2002) demonstrates that involving students in inquiry-based activities only may not enhance their NOS understanding (Abd-El-Khalick *et al.*, 2000; Akerson *et al.*, 2003). Implicit approaches generally do not allow students to reflect on science activities that may assist them to construct understanding of NOS (Abd-El-Khalick *et al.*, 2000b). For instance, Akerson & Abd-El-Khalick (2005) demonstrated that elementary students could not acquire adequate NOS ideas through the inquiry method (Akerson *et al.*, 2005).

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On the other hand, it has further been suggested that learners' NOS views may remain unchanged if no explicit attention is paid to addressing NOS aspects (Bell, Lederman, & Abd-El-Khalick, 2000; Lederman, 2007; Ryder, Leach, & Driver, 1999). The explicit–reflective approach was initially presented by Abd-El-Khalick *et al.* (1998) and improved on by others (Abd-El-Khalick, 2005, 2001; Akerson *et al.,* 2000; Khishfe *et al.,* 2002). These scholars have argued that the explicit–reflective approach encourages planning and inclusion of learning outcomes intended to teach NOS aspects in any science course. Explicit instruction refers to focusing students' dedication to targeted NOS aspects via discussion and written work while engaged in the GI practical activities (Bartholomew *et al.,* 2004; Duschl, 2000; Schwartz *et al.,* 2002).

Inquiry-based instruction has been shown to be inadequate for developing students' NOS understanding (Khishfe *et al.,* 2002). A review by Schwartz *et al.* (2004, p. 616) "strongly suggests that 'doing science' is not sufficient in and of itself for developing informed conceptions of NOS". However, incorporating NOS aspects with a content-based inquiry activity may promote students' understanding of NOS. When teachers incorporate features of NOS with the science content during science instruction, they "contextualize these NOS aspects and make them accessible to students" (Khishfe *et al.*, 2002, p. 574). Furthermore, for students to acquire an informed understanding of different NOS aspects, teachers should create learning environments that may encourage students to participate in both reflective activities and discussions (Schwartz *et al.*, 2002; Schwartz *et al.*, 2004). A significant body of literature corroborates the notion that NOS instruction is beneficial if the instruction has both explicit and reflective characters (Abd-El-Khalick *et al.,* 2000b; Abd-El-Khalick *et al.*, 1998).

In the research study conducted by Schwartz *et al.* (2004) with pre-service teachers, it was realised that reflection may be effective only when NOS aspects are integrated within a context. In their study experiences, the information and descriptions brought by participants in the seminar served as a context. The use of guiding questions and observations improved participants' views of NOS. Although the study by Schwartz and others has been inadequate in promoting better understanding of NOS, incorporating NOS features in inquiry activities may enhance students' NOS understanding (Colburn, 2004).

Previous research studies have demonstrated that explicit-reflective teaching is more efficient in developing learners' conceptions of NOS than implicit instruction (Khishfe *et al.,* 2002; Schwartz *et al.,* 2002). The explicit–reflective approach has been used in professional development programs and discovered to be successful in developing practicing elementary teachers' views of NOS (Akerson *et al.,* 2003; Akerson *et al.,* 2000). A further group of studies (Akerson & Donnelly, 2009; Akerson, Hanson & Cullen, 2007) demonstrated that after using explicit reflective instruction in inquiry-based context, elementary students developed informed conceptions of NOS.

2.4 The role of guiding questions in learning science

Arnold B Arons of Harvard University is one of the forerunners in science education reforms. Arons' research studies were influenced by the ideas of Socrates, Plato, Dewey and Piaget and he was one of the founders of Physics Education Research (PER) in the US. Arons conducted extensive science education research studies on the use of Socratic questioning which may assist students to shift from declarative to operative knowledge. Declarative knowledge involves understanding facts and operative knowledge involves understanding the source of declarative knowledge (Arons, 1983). Arons asserted that teachers should utilise both Socratic questioning and students' experiences to guide students to a superior

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understanding of scientific knowledge, reasoning abilities and logical thinking skills (Hake, 2004). Ausubel (1968, p.504) contended that

> *". . . Providing guidance to the learner in the form of verbal explanation of the underlying principles almost invariably facilitates learning and retention and sometimes transfer as well. Self-discovery methods or the furnishing of completely explicit rules, on the other hand, are relatively less effective. ...The most efficacious type of guidance (guided discovery) is actually a variant of expository teaching that is very similar to Socratic questioning. It demands the learner's active participation and requires him to formulate his own generalizations and integrate his knowledge in response to carefully programmed leading questions, and it is obviously much more highly structured than most discovery methods".*

Scholarly efforts have demonstrated that asking students intellectual engaging questions is often overlooked in classroom teaching (Crow & Stanford, 2010). Nevertheless, questioning as a way of developing new understandings and concepts was established long ago. Socrates used questioning in teaching to assist a student to think, analyse and seek new information (Crockett, 2004).

Asking questions has guided teaching in education for several years (e.g. Crockett, 2004; Hake, 2004). It has been well documented in literature that in a traditional learning environment teachers dominated the classroom talk and little or no time was dedicated to students' thinking (Alexander, 2006; Crow *et al.*, 2010). In many parts of the world, the norm is that teachers pose questions and students are expected to give factual, anticipated answers. However, in inquiry-based science teaching, the questioning process is a critical determining factor in students' learning (Keys, 1998; Watts, Gould, & Alsop, 1997).

Internationally, the trend was to focus on the results due to teachers' questioning strategies on students' science learning. Research shows that different questioning strategies which were used in many countries established that students participating in inquiry-based instruction obtained higher levels of success than students in traditional instruction (Geier, Blumenfeld, Marx, Krajcik, Fishman & Soloway, 2008; Wilson, Taylor, Kowalski & Carlson, 2010).

Researchers refer to assistance offered to students by teachers during the learning process as scaffolding. Scaffolding includes the hints, reminders and encouragement that teachers provide to students to ensure completion of a task during problem solving (Sheppard, 2005). Guiding questions are posed to lead students to a better understanding of the phenomenon being investigated. The questions should be informed by students' prior knowledge to assist them to attain their learning outcomes (Sawyer, 2006).

Through inquiry-based teaching, teachers can use questions to involve students in active learning. The most important aspect of the inquiry approach is the capacity to recognise, inquire and address questions. With guidance, students are able to focus on generating new knowledge and learning useful tactics in each stage of the inquiry process (Kuhlthau, 2010; Kuhlthau, Maniotes, & Caspari, 2007; Kuhlthau & Todd, 2006). The National Science Education Standards describe inquiry-based teaching as engaging students in effective learning that stresses probing, analysing data, and critical thinking.

> *"Students at all grade levels and in every domain of science should have the opportunity to use scientific inquiry and develop the ability to think and act in*

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> *ways associated with inquiry, including asking questions, planning and conducting investigations, using appropriate tools and techniques to gather data, thinking critically and logically about relationships between evidence and explanations, constructing and analyzing alternative explanations, and communicating scientific arguments" (NRC, 1996, p. 105).*

In addition to teachers' questioning strategies, inquiry-based science teaching also encourages students to formulate questions (Oliveira, 2009; White & Gunstone, 1992). Allowing students to generate questions expose students' thinking and their conceptual development (Marbach-Ad & Sokolove, 2000; White *et al.*, 1992; Woodward, 1992), their alternative views (Maskill & Pedrosa de Jesus, 1997) as well as their curiosities (Elstgeest, 1985). It is believed that students' questions may offer "critical incidents for teachers, forge critical reflection about the nature of science and the processes of teaching and learning, and generate shifts in their thinking and classroom practice" (Chin, 2002, p. 522).

In addition, formulation of questions by students may promote reflective learning. Reflection is a widely-used construct in education (Jay & Johnson, 2002; Mueller & Skamp, 2003). Reflection is a multifaceted construct (Hatton & Smith, 1995; Jay & Johnson, 2002) that is essential in inquiry learning (Loh, Reiser, Radinsky, Edelson, Gomez & Marshall, 2001). Harper, Etkina and Lin (2003) established in their study that students with insufficient conceptual knowledge, who ask questions to close the gaps in their thinking, perform better than those who do not ask. In addition, students with relevant prior knowledge ask deeper questions which promote their learning. Regarding the relationship between performance and the type of questions students asked, Harper *et al.* (2003) demonstrated that posing medium to high-level questions enhances conceptual understanding while high-level questioning enhances deeper understanding of the subject content.

According to Shepardspon and Pizzini, (1991) there are three types of cognitive levels of questioning which include: input level, processing level, and output level. The input-level questions encourage students to remember facts. The processing-level questions involve students formulating relations. The output- level questions encourage students to formulate innovative means of drawing conclusions, generalising, synthesising and evaluating. There are several contexts that may encourage students to ask high-level questions (Van Zee, Iwasyk, Kurose, Simpson & Wild, 2001). Firstly, the teacher should create discourse structures that clearly address these questions. Secondly, students should be engaged in discussions regarding familiar contexts which they have observed for a long time. Thirdly, students may be encouraged to ask questions in discourse environments that enable them to understand fellow students' thinking. Lastly, students may ask questions when students collaboratively work together in small groups. According to Miyake and Norman (1979) a student should develop a knowledge structure to formulate a meaningful question and to conceptualise its answer. The National Science Education Standards state that: "Inquiry into authentic questions generated from student experiences is the central strategy for teaching science" (NRC, 1996, chapter 3).

In a classroom science instruction, students should be given the opportunity to reflect on the content they have learnt as well as on how they have learnt the content. The inquiry approach is beneficial because it is student-centred and provides an opportunity for the development of metacognitive skills (Inoue & Buczynski, 2011). In an inquiry learning environment a teacher provides students with an open-ended problem, students should explore answers by designing an investigation process, collecting data, analysing and interpreting the data, and formulating

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an evidence-supported conclusion. According to Brass *et al.* (2003), metacognition is an essential component of the learning process. Metacognition refers to the process of monitoring and regulating one's learning, which is metacognitive control (Pintrich, 2002). Metacognitive control is a cognitive procedure utilised to check and manage thinking and learning and also to promote reflection (Pintrich, 2002). It is via reflection that students may realise their own reasoning and understanding (Mueller & Skamp, 2003; Pintrich, 2002).

Metacognition also refers to an individual's ability to predict performances in various activities and to monitor understanding (NRC, 1999). The metacognitive technique of self-monitoring is an essential tool for developing self-regulated learners (NRC, 2005). Teaching practices are classified as metacognitive if they promote self-assessment on what is successful and what requires improvement. Metacognitive practices extensively enhance an individual's ability to synthesise information and use it in new situations. Students participating in metacognitive practices may be more likely to become self-regulated learners. This implies that students may learn to control and monitor their own learning (NRC, 1999). In the learning process students should be aware of what they understand and what they do not know.

Schon's (1983ab, 1987, 1992) ideas of reflective learning are closely linked to inquiry and learning. Schon differentiates between the ideas of "reflection-in-action" and "reflection-on-action". The former represents reflection during an activity. The latter signifies reflection at the end of an activity, reflecting on what happened, which is associated with the practices of after action reviews and post project evaluations (e.g. Darling, Parry & Moore, 2005; Ron, Lipshitz & Popper, 2006). For example, a student who has observed and reflected on a great deal of evidence justifying the Kinetic Molecular Theory may have more grounds for accepting the theory than a student who has seen little evidence. Deep reflection on evidence may lead to a better understanding of new ideas (Schwartz & Martin, 2004).

During inquiry-based activities, Chinn & Samarapungavan, (2009) further contended that students may undergo foundational changes in their explanatory understandings in the science content (e.g. theories of electricity and magnetism) and foundational changes in reasoning processes (testing a hypothesis and reasoning from the data). Colburn (2006) recommends that the combined use of hands-on inquiry-based activities and guiding questions may encourage the development of students' skills. Kuhn (1977) argued from the philosophical and historical perspectives that the change during a revolution of scientific ideas results in different theories becoming incommensurable.

2.4.1 Previous studies on using guiding questions in the learning of science knowledge

A study by Holmes, Day, Park, Bonn, and Roll (2014) explored the effect of scaffolding on 87 first-year physics students in a lab course. The results in this study showed that, two months after the course, students receiving guided discovery instruction had a better understanding of the concepts than students receiving unguided discovery instruction. The results in this study suggest that scaffolding in the discovery activities followed by teaching may help students develop understanding of subject content knowledge and rectify their failures.

In a study conducted by Blanchard, Annetta, and Southerland (2008), learning gains were compared between inquiry-based and traditional approaches on middle and high school students. The study was comprised of 1800 students and 24 teachers from seven schools. The

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results showed that students taught by GI performed significantly better as compared to students that were taught by traditional methods.

In another study by Lederman (2008), teachers in Sweden and the US taught different units using either GI, direct instruction or a mixed method approach. The mixed approach in this study was more successful compared to GI and direct instruction in enhancing understanding of subject matter knowledge, scientific inquiry and in developing positive attitudes towards science, although the differences were insignificant.

A study by Lewis and Lewis (2008) investigated the impact of GI and direct instruction on undergraduate students' understanding of the subject matter. The results in this study demonstrated that students taught through GI performed significantly better academically than students taught through direct instruction.

Syh-Jong (2007) investigated students' construction of science knowledge through talking and writing in a collaborative environment. It was established in this study that writing and talking in a collaborative environment required students not only to defend their science conceptions but also to incorporate other students' ideas in clarifying their understanding.

In another study, Peer Instruction (PI) was used for a period of more than ten years in the introductory Physics at Harvard University (Crouch, Watkins, Fagen & Mazur, 2007). PI is a teaching approach of involving all students in the learning process using structured questions. It was found in this study that PI promoted students' conceptual reasoning and quantitative problem solving skills.

Chin's (2004, p. 1343) research study on questioning in Singapore showed that "students can be stretched mentally through sensitive teacher-led but not teacher-dominated discourse". O'Loughlin (1992) conducted research in the Baltic nations in Europe, and established that teachers' questioning can guide students to discoveries that cause cognitive dissonance and help them resolve the problem.

The results in these studies demonstrate that the type of questions posed by a teacher during the learning process guide students' cognitive processes.

2.4.2 Previous studies on the effect of some interventions on the understanding of NOS

The results of a number of previous studies of the effect of interventions on the understanding of NOS are summarised in Table 2.2. All three listed literature studies (1 – 3) that compared the pre- and post NOS scores of a group undergoing an explicit reflective NOS course showed a reasonably large effect. One study, in which only an explicit approach was followed, also showed a reasonably large effect in all but one of the aspects investigated. Three studies compared groups taught using aspects of the explicit reflective approach to a control group, where it was found that explicit reflective inquiry is more effective than implicit inquiry and that it was more effective when NOS teaching was integrated with subject matter. GI instruction was found to be slightly more effective than the traditional approach. From these studies, it seems that explicit reflective GI instruction integrated with subject matter is the most effective approach to teaching NOS. The detailed analysis of results in these studies can be found in the Appendix L.

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Table 2.2 Comparison between the effects of various interventions on participants' views of NOS, as investigated by previous studies

			Effect on understanding NOS (pp)*						
Nr	**References**	**Type of intervention**	**TN**	**IC**	**TL**	**SC**	**SM**	**EN**	**OI**
1	Yacoubian & BouJaoude (2010)	Reflective discussions & inquiry-based laboratory activities (pre vs. post), grade six students in Lebanon	–5	–	–	36	–	39	–
2	Morrison, Raab & Ingram (2009)	Explicit reflective NOS & professional development course (pre vs. post), elementary teachers in the USA	30	50	5	20	–	5	15
3	Khishfe & Abd-El-Khalick (2002)	Explicit-reflective inquiry- approach (pre vs. post), sixth-grade students in Lebanon.	46	34	–	–	–	39	20
4	Yalçinoğlu & Anagün (2012)	Explicit NOS course (pre vs. post), elementary science teachers in Turkey	16	10	0	19	–	–	15
5	Çıl, (2014)	Explicit reflective vs. implicit inquiry, Seventh grade students in Turkey.	33	6	–	–	–	5	17
6	Sharif & Hasan (2012)	Guided-inquiry instruction vs. traditional approach, tenth grade students in Dubai	–	–	0	–	14	–	–
7	Khishfe & Lederman (2007)	Integrated vs. non-integrated explicit teaching of NOS, ninth, tenth & eleventh grade students in the USA	18	27	–	–	–	15	19

2.5 Conceptual framework

The current study is underpinned by a constructivist philosophical perspective, especially the theoretical basis of Piaget's (1972) Theory of Cognitive Development and Vygotsky's (1978) Sociocultural Theory. Piaget's (1972) theory proposed that learners organise their knowledge into schemas and process learning through transforming these schemas to understand new experiences. When learners encounter new experiences, they attempt to understand by assimilating the new experiences into a prior knowledge schema to attain a state of cognitive equilibrium. Put differently, according to Piaget students learn by interacting with their environment, other students, and teachers, and by transforming those experiences into their schemas through assimilation. Vygotsky's (1978) Sociocultural Theory emphasised the pivotal role of the language and social interactions in the facilitation of meaningful learning and cognitive development in a learning environment.

As discussed earlier in Section 1.8.1, students' learning in the PbI curriculum (McDermott *et al.*, 1996) is facilitated by guiding questions and the teaching approach utilised is GI. PbI was selected for this study because of the two critical reasons. Firstly, science teaching is promoted by asking guiding questions. Secondly, the fundamental aspect of PbI is that of encouraging students to apply their acquired knowledge and skills in various settings.

The phases of scientific inquiry (formulation of scientifically informed questions, gathering of data to answer the problem, analyses and interpretation of data, drawing of conclusions and linking them to other research findings and presentation of the findings) are embedded in the PbI model. However, extensive literature (e.g. Abd-El-Khalick & Akerson, 2004; Akerson *et al.*, 2003) suggests that the explicit reflective approach may promote the development of NOS and scientific reasoning skills. The whole process is not sequential but cyclic and is expected to give rise to deep learning and understanding of science concepts as well as improved performance in science (Anderson, 1997; Von Secker, 2002).

Figure 2.1 represents a conceptual frame based on the assumption that the PbI model with ERQs may bring about changes in first-year physics students' conceptual learning and understanding of science, students' art of experimentation, academic performance, collaborative learning skills as well as attitudes towards laboratory work. The conceptual model for the current study shows that the combination of PbI laboratory practical activities and ERQs should lead to deep conceptual learning and better understanding of science knowledge, which should improve the understanding of NOS, students' art of experimentation and academic performance, collaborative learning skills as well as attitudes towards laboratory work.

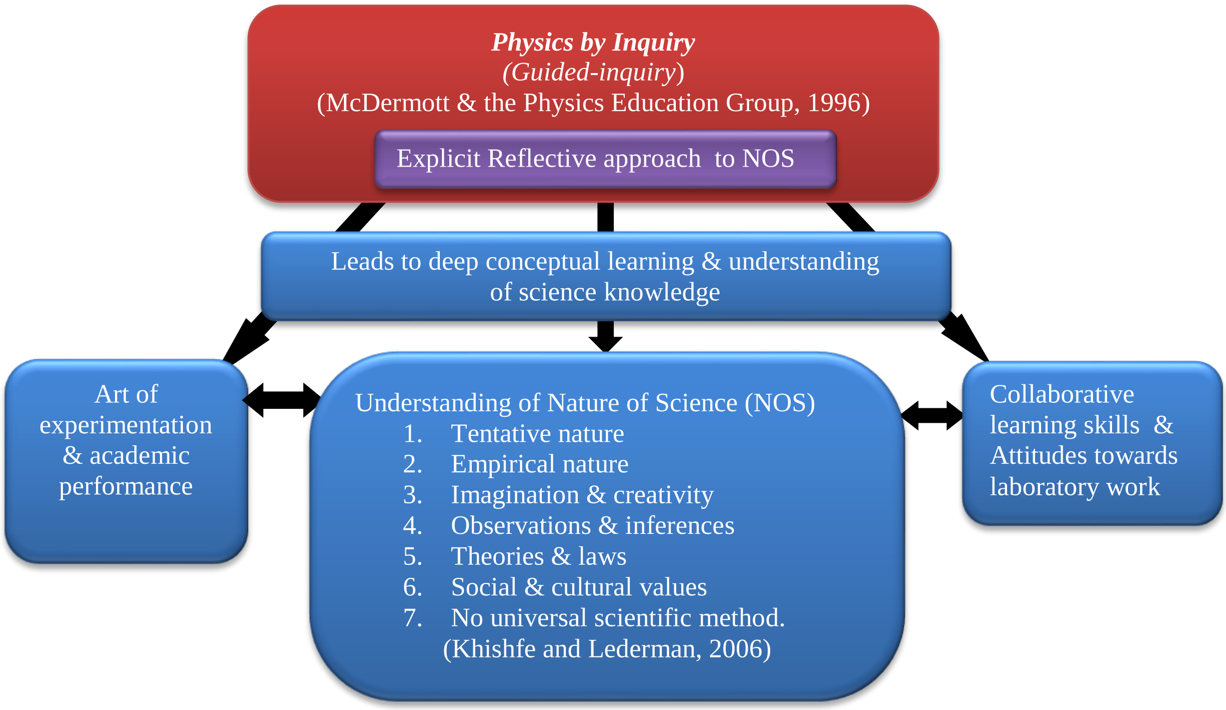

Figure 2.1 A conceptual framework showing the relationship between guided-inquiry based instruction, nature of science, art of experimentation, academic performance, collaborative learning skills as well as students' attitudes towards laboratory work.

The current study investigates if the explicit reflective approach and the PbI enhance students' understanding of the seven aspects of NOS, students' art of experimentation and academic performance in science, collaborative learning skills as well as attitudes towards laboratory work.

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Chapter 3: Methodology

In this chapter, the methodology used in the current study is discussed. Methodology is an approach which supports the choice and use of certain methods (Crotty, 1998), addressing questions such as why, what, where, when and how data are gathered and analysed. The chapter starts with a discussion of the paradigm guiding the study, followed by a discussion of the design and approach of the study. Next, the sampling procedure is discussed, followed by the discussion of data collecting procedures. Next, the analysis of data, collected by the various instruments, will be discussed. Finally, the trustworthiness of the study, as well as ethical considerations, is discussed.

3.1 Philosophical worldview

The present study subscribes to pragmatism. Pragmatism has been defined in numerous ways across literature. For instance, pragmatism is considered as a philosophical position that assumes a role of solving practical problems in the real world (Feilzer, 2010; Gray, 2009). Gray (2009, p.3) posited that, "… the real world comprises of any setting where human beings come together for communication, relationships or discourse". In addition, pragmatism is believed to be an action-oriented philosophy of science (Dewey, 1929; James, 1907; Peirce, 1992) which explores the relationships either between action and truth or between custom practice and theory. Dewey (1931, p. 31) defines pragmatism as "the doctrine that reality possesses practical character". Put differently, pragmatists perceive the world as set of practical activities that develop from ideas or thinking (Ormerod, 2006). Philosophical pragmatism supports that "…ideas and practices should be judged in terms of their usefulness, workability and practicality" (Rorty, 2006, p. 104).

Dewey's pragmatism may be understood as embedded in the philosophy of revolutionary changes caused by human beings. Dewey described thinking and reflection as "means of conducting transformational transactions with the world, a means of changing or reconstructing the world" (Sleeper, 2001, p. 3). Pragmatist philosophy occurs in real-life situations, where changes are constantly occurring and where man is considered as an instrument of change and a contributor to transformations, either through thought or action. In pragmatism, scientific theories and thinking manifest into ideas that are applied in real-life contexts (Maxcy, 2001). Peters (2007) argues that theory and practice are not separate but intertwined. Ormerod (2006) demonstrates that the fundamental idea of pragmatism is that beliefs developed by individuals are guides to actions. Another important aspect of pragmatism is that it supports abductive reasoning, meaning that methods of inquiry are guided by the situational needs, such as the development of new understandings during the investigation process. Thus, according to Miettinen (2006, p. 400) "Pragmatism regards practical experimentation and intervention as an essential part of studying human practices". Therefore, the pragmatic view is appropriate to this current study where an intervention has been implemented in a quasi-experiment.

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Pragmatism is practical and relates to post-positivism as well as interpretivism in the current study. Post-positivism underlies the investigation of possible cause and effect relations between the ERGI laboratory practical activities and the outcomes of a first-year Bachelor of Science course (Creswell, 2009; Elkjaer & Simpson, 2011). These include specifically the effect of combining explicitly-reflective guiding questions and GI laboratory activities on students' understanding of NOS, academic performance and students' attitudes towards the laboratory work. Interpretivism underpins the aspects of students' understanding of NOS and their attitudes towards laboratory work. The two paradigms, postivist and interpretivist were used in the current study in order to develop a deep understanding of the problem under investigation. Interpretivist paradigm stands in contrast to the postivist paradigm in which quantitative results were analysed and enabled the researcher to investigate the effect of ERQs combined with GI on students' understanding of NOS. The interpretivist paradigm enabled the researcher to understand how students socially experienced GI vs traditional recipe-based practical activities and how it influenced their attitudes. This was implemented specifically in the FGI.According to Cohen and Manion (1994, p.36), the interpretivist paradigm provides an opportunity to understand "the world of human experience", which further confirms that "reality is socially constructed" (Mertens, 2005, p. 12).

In the current study, students in the control group performed traditional recipe-based practical activities, while students in the experimental group were guided in conducting investigations, gathering, analysing and interpreting data, and drawing conclusions. This study is exploring the possibility that guiding questions together with the ERGI laboratory practical activities promote the development of critical and creative thinking skills, the discovery of natural laws, translating learned skills into a new situation and developing positive attitudes towards science learning. Put differently, students were provided with tools to actively engage in the construction of knowledge and meanings relating to experiences acquired through participation in GI-based physics laboratory activities. The knowledge and skills acquired may be used to address real-life problems associated with science and technology (Ardalan, 2008). In addition, students may actively participate in debates relating to socio-scientific and technological issues. It is assumed that these skills will be measurable in the effect of the ERGI laboratory practical activities. The cause-effect relationship investigated here is based on a post-positivist paradigm and a pragmatic worldview.

3.2 Research design

The primary focus of the current study was to investigate the effect of ERGI laboratory practical activities on the outcomes of the first-year physics course. Therefore, a quasi-experimental design was implemented using students in a first-year physics course at a specific university. Students in the experimental group were involved in the inquiry-based laboratory practical activities while the control group performed traditional recipe-based practical activities. The study was experimental research since there was a planned intervention involving the manipulation of variables (redesigning recipe-based laboratory practical activities into inquiry-based format) to establish any causal relationships (that is, the effect of the ERGI laboratory practical activities on students' understanding of different aspects of NOS, students' academic performance and students' attitudes towards laboratory work.)

The current study followed a quasi-experimental design using a mixed methods approach (Creswell, 2007, 2009; Trochim, 2006). The study made use of a mixed methodology which integrates features associated with both qualitative and quantitative approaches (Creswell,

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2003; Erickson, 1998; Tashakkori & Teddlie, 1998). A quantitative approach was used in the analysis of the scores obtained in these curricular activities (e.g. combined practical examination and theoretical year-end examination mark). Qualitative data were transformed into quantitative data to assess the understanding of NOS. In short, the integration of findings from both methods has allowed the researcher to better understand the effect of ERGI laboratory practical activities on first-year physics students' outcomes. Several data sources were used to develop a better understanding of the nature of students' NOS views as well as their performance in the in various aspects of the course (i.e. written practical examination, hands-on practical examination and the theoretical year-end examination.)

3.3 Research approach

The current study followed a mixed methods approach using a concurrent nested design (Caracelli, & Greene, 1997). The experimental design was nested, as one group of students received on treatment, while the other group received another treatment. This is in contrast to a cross-over design, where both groups would receive both treatments (Stockburger, 1996). In this design, qualitative and quantitative data were gathered simultaneously and analysed together. This approach was relevant to the current study since different aspects (e.g. understanding of NOS, academic performance and attitudes towards laboratory work) influenced by the ERGI laboratory practical activities, were studied (Tashakkori & Teddlie, 2003). The mixed-methods approach allowed for a better understanding of both the range and nature of students' outcomes in physics. Johnson and Onwuegbuzie (2004, p.17-18) described mixed methods as:

> *"The class of research where the researcher mixes or combines quantitative and qualitative research techniques, methods, approaches, concepts or language into a single study. Mixed methods research also is an attempt to legitimate the use of multiple approaches in answering research questions, rather than restricting or constraining researchers' choices (i.e. it rejects dogmatism). It is an expansive and creative form of research, not a limiting form of research. It is inclusive, pluralistic, and complementary, and it suggests that researchers take an eclectic approach to method selection and the thinking about and conduct of research".*

In addition, Caracelli *et al.* (1997) suggested three functions of a mixed method study namely: (1) verifying the agreement of results found by using different tools, (2) illuminating and elaborating on the results obtained by using one method with another and (3) showing how findings from one approach may affect later methods or conclusions formulated from the findings. It is against this background that Greene, Caracelli, and Graham (1989) advanced five reasons for using mixed methods. Firstly, triangulation, which investigates the consistency of findings, generated by different instruments such as an open-ended questionnaire, focus group interviews (FGI) and combined practical examination (comprised of a written practical examination and a hands-on practical examination). Secondly, qualitative and quantitative data findings complement each other to address different features of the phenomenon under investigation (for instance, an open-ended questionnaire and FGI). Thirdly, progress in which findings from one method may influence steps in the research. Fourthly, initiation, in which findings from one method encourage new directions for the research. Finally, growth, which may explain and add depth to the results.

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Furthermore, Caracelli & Greene (1993) outlined the four cases where a mixed methods approach can shed more light on data during the analysis phase. Firstly, transformation of data, in which qualitative data are either transformed into quantitative data or qualitative data transformed into narrative and the final data are analysed. Secondly, development of typology or a set of categories, in which the analysis of one type of data creates typology for analysing the subsequent type of data. Thirdly, analysis of extrema, in which extrema in one type of data could be explained by the complementary type of data. Fourthly, consolidation of data, in which evaluation of both qualitative and quantitative data may result in the development of new variables expressed in a qualitative or quantitative metric. The consolidated data may be used in further analyses. The current study followed the first and second strategies, by firstly quantifying questionnaire data and secondly analysing focus-group interviews. Purely quantitative data analysis was employed for interpreting academic performance.

3.4 Research paradigm

The post-positivist research paradigm supports the investigation of cause and effect relations between the ERGI laboratory practical activities and students' outcomes in the physics course. The post-positivist paradigm assumes that, "… the social world is patterned and that causal relationships can be discovered and tested via reliable strategies," (Hesse-Biber & Leavy, 2011, p. 5). Inherent in this paradigm is the existence of objective reality beyond human conception (Lincoln & Guba, 1985). It also assumed that researcher's perspectives, experiences and biases should not influence the conduct of the research study.

The post-positivist perspective uses deductive reasoning based on existing theories (Creswell, 2009). Researchers, according to the post-positivist perspective, are likely to utilize several perspectives. The post-positivist paradigm refers to a change of thinking from traditional positivist's view of absolute truth (Phillips & Burbules, 2000) to a view that there is a multiple of realities when conducting research on human interactions (O'Leary, 2004). The post-positivist paradigm is "based on the rationalistic, empiricist philosophy that originated with Aristotle, Francis Bacon, John Locke, August Comte, and Emmanuel Kant" (Mertens, 2005, p.8) and "reflects a deterministic philosophy in which causes probably determine effects or outcomes" (Creswell, 2003, p.7).

Scores of different tests were statistically analysed to compare the two groups. The following comparisons between control and experimental groups were made:

- Percentage of students expressing informed, mixed and naïve views on each NOS aspect,
- Percentage of students expressing informed, mixed and naïve views per NOS aspect, for the males (M) and females (F),
- Percentage of the high (H) achieving and low (L) achieving students expressing informed, mixed and naïve views per NOS aspect,
- Average scores obtained by students in the individual questions in the written practical examination,
- Average scores obtained by the academically high and low achieving students in the individual questions in the written practical examination and the theoretical year-end examination.

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Apart from the numerical comparisons, attitudes towards laboratory work were also compared for students in the control and experimental groups.

3.5 Sampling

The study explored the effect of the ERGI laboratory practical activities on outcomes achieved in a first-year BSc physics course. All students were invited to give consent that their activities in the laboratory course might be used as data in the study. Convenience sampling was used as the population was directly available to the Department of Physics (Miles & Huberman, 1994). The population of the current study included all the BSc first-year physics students who have enrolled for the second semester of the mainstream, calculus-based physics course in the Bachelor of Science (BSc) degree program. A total of 220 students enrolled for the course, with a male to female ratio of 3:2. There were 132 males and 88 females. All the students selected for the study were 18 years or older (mode 19, average 20) and had been taught science mainly through traditional methods. The large majority of the students were South Africans.

Ninety-seven students consented to participate in the study and were systematically assigned (Trochim, 2006) to either experimental or control groups. This procedure is believed to select two probabilistically equivalent groups so that any differences, after the practical course, may be ascribed to the difference in the practical activities. Systematic sampling was used, in which every second student on the alphabetical class list was assigned to the experimental group, while the rest were assigned to the control group. Since no pattern relating to odd or even position was expected in the alphabetical list, this sampling method may be considered to yield similar results to simple random sampling (Trochim, 2006). Those students who did not give consent to participate and those students that enrolled late were excluded from the study.

This was a post-test-only control-group design. Such designs are used when conducting a pre-test is not desirable or feasible (Campbell & Stanley, 1996; Gall, Borg & Gall, 1996; Moazami, Bahrampour, Azar, Jahedi & Moattari, 2014). In such cases it is essential that the groups are probabilistically equivalent, such as in random or systematically assigned groups. In this study, random assignment to the groups was not done, but systematic assignment to groups ensured their probabilistic equivalence.

Typical situations for not conducting pre-tests are time constraints, financial constraints, test fatigue and test sensitisation (Gall, Borg & Gall, 1996; Riccardi, Marinuzzi & Zecchin, 1998). In the current study, constraints on the access to the students for testing in a full academic programme precluded the administering of a pre-test – in fact, it was difficult to schedule a time slot for the post-test. There was also a significant risk of students dropping out of the study if they were forced to do too much extra work, especially at the start of the course. (Already only 50% of the class agreed to participate.) Furthermore, a pre-test could sensitize the students to the intended outcome and would potentially induce students answering according to the expectations in the post-test. In fact, in a previous trial done before this study, clear signs of test familiarity or test fatigue were observed, in that students often answered the VNOS questions in the post-test with significantly less detail than they did a year before (Baloyi, Meyer & Gaigher, 2016).

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Another reason for not conducting a pre-test is that the study was not interested in students' initial understanding of NOS but rather interested in the difference in the outcomes of the two different types of laboratory activities. The aim was to observe the relative advantage of one group over the other, so, assuming that the control group and the experimental group were probabilistically equivalent at the start of the intervention, differences in the post-test may be ascribed to the difference in treatments of the two groups. Finally, it was also seen as ethically unjustifiable to take student's time writing a non-essential pre-test. During the study, no students asked to be removed from the study, however, 13 students were not included in the study since they dropped out of the course. At the end of the study, the control group consisted of 33 males and 8 females, while the experimental group consisted of 31 males and 12 females.

The experimental and control groups were further subdivided into smaller laboratory groups of about 25 students, who performed their laboratory activities together in a laboratory under the guidance of laboratory assistants. Each laboratory was equipped with 15 experimental set-ups. Students worked together in small working groups of three (maximally four). To ensure greater cumulative effect over a period and to prevent contamination, students were required to stay in the groups to which they were originally assigned. Where, due to an individual student's circumstances, a change of group was essential, the student's results were not included in the study.

The groups were arranged in a cross-over sequence E C C E, where E represents the experimental group and C the control group. This sequence was viable since similar practical activities were covered with both groups of students, except that they followed different approaches. The students, that did not consent to be included in the study, were assigned to separate groups that did the same experiments as the control group and which were interspersed between the other groups, so the final group order was E, N, C, N, C, N, E, N, where N represents groups that were not part of the study. Therefore, no group was in a more advantageous position in comparison to the others.

3.6 Data collection

Both qualitative and the quantitative data were gathered during and at the end of the ERGI and traditional recipe-based laboratory practical activities, in order to answer the research question. In this mixed methods study, different types of qualitative and quantitative data were collected using different instruments as discussed below, to answer the different subquestions. Qualitative data were collected by open-ended questionnaire and quantitative data were gathered using a combined practical examination (i.e. written and hands-on practical examinations) as well as a theoretical year-end examination. Initially, we intended to use the VNOS test both pre- and post- practical activities. However, due to time pressure and concerns regarding test fatigue, students only wrote one open-ended VNOS Form-C questionnaire at the end of the course. The students also wrote a combined practical examination which comprised both a hands-on as well as a written section. In addition, students were invited to a focus group interview.

3.6.1 Open-ended questionnaire

An open-ended questionnaire, VNOS-Form C, developed by Lederman et al. (2002) was used to determine students' understanding of NOS, in order to answer subquestion 1. The VNOS-C questionnaire was developed and validated for use with undergraduate students and

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teachers by Lederman *et al.* (2002). Additionally, the face and content validity of the VNOS-C was ascertained by a panel of experts (Abd-El-Khalick, 1998) while construct validity of the VNOS-C had been determined by comparing expert and novice groups' views of NOS (Bell, 1999). The VNOS-C questionnaire had been widely used with in-service and pre-service teachers (Abd-El-Khalick, 2001; Abd-El-Khalick *et al.*, 2000; Lederman *et al.*, 2001; Schwartz, Lederman, & Crawford, 2000).

This instrument requires students to answer ten open-ended questions that test their views on the seven NOS aspects (Khishfe *et al.*, 2006). The VNOS-C questionnaire was a suitable instrument due to its open-ended nature which allowed data collection with the intention of describing students' views on NOS as required by the study. Being open-ended, it provided participants with an opportunity to express their views using their own expressions, without being compelled to choose words that have been phrased for them in forced-choice instruments (Lederman *et al.*, 2002; Schwartz *et al.*, 2004).

To establish whether there were any misinterpretations of the VNOS-C questions and ambiguous responses, FGI were performed after administering the VNOS-C, as recommended by Schwartz *et al.* (2004). The focus group sessions are discussed in the next section.

3.6.2 Focus group interviews

A focus group interview is a semi-structured group discussion usually conducted in an informal setting intended to gather participants' understandings, experiences, attitudes and beliefs on a topic by exchanging views in group discussions (Kitzinger, 1994, 1996; McLafferty, 2004). In the current study, conducting FGI had two aims: Firstly, to validate data gathered through the VNOS questionnaire, as suggested by Lederman (1992) and Lederman and O'Malley (1990) and, secondly, to compare the experiences of students in the experimental and control groups, to answer subquestion 2.

Although all students were invited by e-mail, only sixteen students responded and were interviewed, there were 9 females and 7 males. Seven students out of sixteen were from the experimental group, engaged in the ERGI laboratory practical activities while the other nine were from the control group, engaged in recipe-based practical activities. Table 3.1 summarises the biographical details of the participants in the focus groups.

The volunteers were divided into four focus groups (Krueger, 1994) with four students (Krueger & Casey, 2000) per group. In this way, both the control and experimental groups were represented in each focus group.

Firstly, the focus groups were given intellectually engaging questions derived from the VNOS-C questionnaire to discuss. Students were given the opportunity to respond individually and then the group was given an opportunity, in a round table discussion, to comment and find further clarity.

This helped the researcher to draw up a clear representation of participants' understandings of different aspects of NOS (Schwartz *et al.*, 2004). Later in the interview, questions addressing the experience of the students during the practical course were posed and discussed. The

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Table 3.1 Summary of Biographical details of the Students Participating in the Focus Group Interviews.

Participant code	Gender	Group (E/C)	Age	Course	Race (Black/ White)	Practical Mark (%)
V3	F	E	19	BSc – Chemistry	White	67
V8	F	E	18	BSc –Physics	White	84
V13	M	C	19	BSc – Physics	White	51
V15	M	E	19	BSc –Computer Science	White	84
V17	M	C	20	BSc –Computer Science	Black	88
V19	F	C	19	BEd –Natural Sciences	Black	50
V21	F	E	19	BSc – Chemistry	Black	59
V23	F	E	20	BSc – Chemistry	Black	68
V39	F	E	22	BSc – Mathematics	Black	41
V44	M	C	20	BSc – Physics	White	60
V49	F	C	19	BSc – Chemistry	White	90
V51	F	C	20	BSc – Physics	White	69
V54	M	C	19	BSc – Physics	White	71
V59	F	E	19	BSc – Meteorology	Black	59
V61	M	C	20	BSc – Physics	Black	69
V66	M	C	22	BEd –Natural Sciences	Black	56

interview process was guided by the work of Bogdan and Biklen (1992) and Clough (2007) through asking students guiding reflective questions.

Group discussions and interactions amongst students during FGI facilitated expression of experiences, attitudes, meanings, opinions, knowledge and ideas about the ERGI and traditional recipe-based laboratory practical activities which might not be obtained by individual interviews (Wilkinson, 1998). Each interview lasted for approximately 60 minutes. The interviews were videotaped and transcribed for analysis.

3.6.3 Explicit reflective questions

ERQs were formulated by the researcher together with the supervisors using VNOS–C questions as guidelines.Students' answers were used as validation of the VNOS answers, thereby contributing to subquestion 1. These questions were formulated using the scientifically historical events surrounding the development of science knowledge (Abd-El-Khalick, 1998) and were contextualised to all eight physics laboratory practical activities (see Appendix G).

These questions were placed at the end of the practical worksheets of both groups and counted marks in both cases, in order to encourage students to take the time to answer them carefully.

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3.6.4 Combined practical examination

At the end of the semester, a combined practical examination was given, which covered all the experiments conducted during the semester. The combined practical examination consisted of two sections: a hands-on practical examination and a written practical examination about the practical tasks (see Appendices J and K). Care was taken to ensure that any questions asked had been sufficiently covered by both experimental and control groups. The mark for the combined practical examination counted 50% of the final practical mark of the students (the other 50% of the practical mark represents marks earned during the practical session throughout the semester). To prepare for this examination, marked worksheets were returned to the students. The combined practical examination was used to measure the extent of the students' understanding of the practical work and their mastery of the measuring and data processing skills involved, thereby answering subquestion 3. The marks for the hands-on practical examination and a written practical examination were added to obtain a combined practical examination score.

3.6.5 Theoretical year-end examination

The results of the theoretical year-end examination in the physics course were used as a measure of students' academic performance, thereby answering subquestion 4. The effect of the ERGI laboratory practical activities on students' academic performance was determined by comparing the results of the experimental and control groups.

3.7 Data analysis

3.7.1 Open-ended questionnaire

In the current study, the questionnaire focused on the seven aspects of NOS (Lederman, *et al.*, 2002) as discussed in Section 2.3. Evaluation of students' responses was based on a description of informed views of NOS by Lederman *et al.* (2002) and Schwartz *et al.* (2004). The scoring was therefore grounded in the evidence but based on Lederman's (1992) definition of NOS and the different features of NOS.

The students' responses were coded using a scoring rubric (see Appendix I) developed by the researcher based on the guidelines for scoring the VNOS-C (Lederman *et al.*, 2002). The decision to develop a rubric for VNOS-C for the current study was inspired by a rubric for the VNOS-D designed by Akerson and Donnelly (2010). Adapting the VNOS-C scoring guidelines into a rubric format simplified the scoring procedure. The rubric enabled the researcher to analyse and evaluate students' responses objectively, and helped him focus on the key words and phrases addressing seven NOS aspects as described by Lederman *et al.* (2002).

According to the rubric, each response was classified as either a naïve, a mixed or an informed view of NOS. According to Lederman, *et al.* (2002, p. 512) there are "key terms or phrases" from the students' responses that can be used as guides to evaluate students' understanding of the seven NOS aspects. For example, some of the key words considered included "test", "procedure" and "investigate" which demonstrate a more informed view of the VNOS aspect "no universal scientific method". Conversely key words or phrases such as "prove a theory or law", "test a theory or law" and "a fact" demonstrate naïve views of this NOS aspect.

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The VNOS-C questions have a generic nature. Thus, a single question could probe more than one aspect of NOS, and most aspects of NOS were addressed by more than one question. For instance, the tentative nature and the influence of imagination and creativity in the generation of science knowledge are addressed by VNOS-C 1, 5, 6 and 8. By examining students' consistent use of key terms and phrases in different questions, a deeper insight into the students' understanding of different aspects of NOS is obtained, compared to the case where only a single question is used. In establishing the profiles, the participants who answered naïvely on an aspect in different questions addressing that aspect were considered as naïve, while the participants who gave informed views on an aspect in at least one question addressing that aspect were categorised as informed. The participants having mixed views on a specific aspect in different questions were classified as mixed.

Due to the subjective nature of the evaluation and the effect of evaluator bias, it was decided to evaluate the results of the two groups blindly – i.e. all the identifying information (including the group the student belonged to) was hidden from the evaluator. Also, the answers were read and scored in a random order for each student. To enhance validity and reliability (Strauss, 1987) scoring was reviewed during several rounds of discussions between the researcher and supervisors to reach consensus. The bulk of scoring was completed by the researcher.

3.7.2 Focus group interviews

The interviews were structured firstly to complement the VNOS-C questionnaire in probing the students' views about the meaning of science, science knowledge, the importance of evidence in science and the scientific endeavour. Secondly, the aim was to explore the impact of the ERGI laboratory practical activities on students' experiences of collaborative investigation and learning in the physics laboratory. In the case of questions on NOS, the responses were organised in the same categories as used for VNOS-C because the students' views surpassed the individual questions. For instance, the first question asked about the meaning of science, however, students additionally gave indications of their understanding of science knowledge in response to the subsequent questions (i.e. third, fourth, fifth and sixth questions). Consideration of students' responses to only the question directly addressing the aspect, would have excluded useful data during the analysis phase.

Discussions captured in the video recordings of FGI were transcribed in full in a text file. The procedures described by Lesh and Lehrer (2000) were used when analysing the transcriptions. The transcriptions were read several times and analysis refined as meaning became clear. The transcriptions were coded anonymously, and analysed for differences in students' experiences of GI and traditional recipe-based practical activities as well as their NOS understanding. Answers to the questions on NOS were categorised as naïve, mixed or informed based on the same rubric used to score the VNOS-C questionnaire. An essential feature of qualitative analysis is the search for patterns that unite previously isolated occurrences. The search for patterns allowed the researchers to explore similarities and differences between the experiences of students doing recipe-based and students doing GI practical activities.

During the FGI students were asked different questions regarding their experiences of the practical course (see Appendix H). The student's responses were captured on video carefully transcribed. The student responses were read several times and the emerging ideas were classified in different categories according to their experiences acquired from either GI

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combined with ERQs or traditional recipe-based practical activities with ERQs. Emerging trends were identified according to the interpretivist paradigm.

3.7.3 Explicit reflective questions

As discussed in Sections 3.7.1 and 3.7.2, respectively, the students' responses to ERQs were evaluated using a scoring rubric (see Appendix I) designed by the researcher and each response was classified as either a naïve, a mixed or an informed view of NOS.

3.7.4 Combined practical examination

The combined practical examination forms part of the normal curricular activities of the Physics Department. Therefore, the marking was done by laboratory assistants as in previous years. The results were analysed statistically by the researcher to compare the performance of the experimental and control groups.

3.7.5 Theoretical year-end examination

The theoretical year-end examination forms part of the normal curricular activities of the Physics Department. Therefore, the marking was done by lecturers as in previous years. The results were analysed statistically by the researcher to compare the performance of the experimental and control groups.

3.7.6 Statistical analysis

Statistical hypothesis testing was used to determine if observed differences were statistically significant. i.e. to test the null hypothesis H_0: $p_1 = p_2$ versus the alternative H_A: $p_1 \neq p_2$, where p_1 and p_2 are the proportions of informed views in the two populations under consideration. Since, in principle, the ERGI laboratory practical activities could have had a positive or a negative effect, it was decided to use a two sided test. Since the samples were relatively small, it was decided to make use of Fisher's exact test everywhere, except when the overall NOS score was compared and much data were available therefore the normal approximation was valid. The level of significance α was chosen as 0.05.

In the current study, students were tested on their understanding of the seven aspects of NOS (TN, EN, TL, OI, IC, SC, and SM). When conducting multiple testing, the first idea involves testing each hypothesis separately using some level of significance (α). Since there are seven NOS aspects investigated, seven individual hypothesis tests had to be performed. However, doing 7 hypothesis tests increases the probability of H_0 being rejected even if it is true. This problem is addressed by the Bonferroni correction for multiple testing (Dunn, 1961) according to which α (0.05) should be divided by the number of hypotheses tested. Since the students' understanding of seven NOS aspects were investigated in the current study, then the significance level will be given by 0.05/7 = 0.0071.

In order to avoid this problem, it was decided to test only the single hypothesis regarding the difference in average NOS score between the control and the experimental group, as this would use the greatest amount of data, and would be the most important aspect of the paper. Further tests were done and p-values quoted to give an indication of the significance of the tests. These values should however be interpreted keeping the Bonferroni Correction in mind.

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3.8 Trustworthiness

As discussed in Section 3.6.1, validation of the VNOS questionnaire for undergraduate students is reported in the literature and therefore the questionnaire was considered a valid instrument to be used in the current study. Furthermore, the use of a blind scoring of the VNOS questionnaire minimised the effect of researcher bias.

Similar to reports in the literature, FGI substantiated and clarified the students' views obtained through the written VNOS questionnaire. Furthermore, students' answers to ERQs also supported data from the VNOS questionnaire. This agreement between the results from multiple data sources represents triangulation, thereby improving the trustworthiness of the findings (Denzin, 1970).

Through the systematic assignment of students, to the experimental and control groups, respectively, systematic bias due to group assignment was prevented. Contamination between groups was minimised by separating the experimental and control groups during practical activities. The same topics were covered in the experimental and control groups, however the control and experimental groups used different worksheets, which they were not allowed to take out of the laboratory.

Care was also taken to ensure that the laboratory assistants did not inadvertently cause bias in the system. Many of the current laboratory assistants were conversant with the management of traditional recipe-based laboratory activities. Therefore, these laboratory assistants were trained on how to facilitate the inquiry-based practical activities. They were trained on how to deal with some of the challenges that they might encounter during the practical sessions, such as assisting students struggling to do tasks required by an inquiry-based practical activity. For the sake of treatment fidelity, elimination of the teacher effect and smooth running of activities, the preferences of laboratory assistants regarding inquiry and traditional methods were not considered when assigning assistants to experiments and groups. Instead, each of the eight laboratory assistants presented one specific practical activity to both groups. The practical sub-groups were assigned their experiments on a rotation basis. Therefore the same assistants taught the same practical to each group. Furthermore, the groups were spaced as "E X C X C X E X" (where E = experimental group, C = control and X = non-participating group, taught according to the control group), thereby evening out both the teacher effect as well as the effect of being the first or last to do a specific experiment (Allen, Gregory, Mikami, Lun, Hamre., & Pianta, 2013; Brophy, 1986; Sanders, & Rivers, 1996). Assistants were reminded beforehand to teach according to the approach required for the given group, and the researcher observed that the assistants taught according to these requirements. The assistants did also not at any stage teach NOS explicitly to any group.

Also, all tests, including the VNOS test were scored blindly, with the scorer not being able to identify the student or the group to which he belongs.

During the study, the instructional method of the assistants was monitored to ensure that they kept to the required regimen. Specifically, the risk of assistants assigned to the experimental group falling back to a recipe-based approach was foreseen and was specifically monitored for. Therefore, laboratory assistants were required to critically reflect (Alfaro & Quezada, 2010) on their guidance provided during each practical session. These reflections showed that these assistants succeeded in providing suitable guidance for inquiry-based practical

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Table 3.2. Alignment of research questions, paradigms, methodology, data collection instruments and analysis

<table>
<tr><th colspan="2">Research questions</th><th>Paradigms</th><th>Methodology</th><th>Data collection instruments</th><th>Analysis</th></tr>
<tr><td rowspan="4">To what extent do guided inquiry-based laboratory activities and ERQs promote BSc Physics students':</td><td>Understanding of NOS?</td><td rowspan="2">Interpretivism</td><td rowspan="2">Qualitative</td><td rowspan="2">VNOS-Form C and focus group interviews</td><td rowspan="2">Coding, generation & description of themes, comparison & interpretation of themes.</td></tr>
<tr><td>Attitudes towards laboratory work?</td></tr>
<tr><td>Conceptual development?</td><td rowspan="2">Post-positivism</td><td rowspan="2">Quantitative</td><td>VNOS-Form C
Combined practical examination</td><td rowspan="2">Numerical scores were statistically analysed and compared. Differences between experimental and control groups were investigated.</td></tr>
<tr><td>Academic performance?</td><td>Theoretical year-end examination</td></tr>
</table>

activities. The measures discussed above, such as validation of instruments, data triangulation, systematic assignment to groups and treatment fidelity, support the credibility of the study.

The research questions along with the applicable paradigm, methodology, data collection instruments and analysis technique are summarised in Table 3.2.

As discussed earlier, laboratory assistants in the current study were reminded beforehand to teach according to the approach required for the given group (i.e. traditional recipe-based approach for the control group and GI approach for the experimental group). The assistants did also not at any stage teach NOS explicitly to any group.

Also, all tests, including the VNOS test were scored blindly, with the scorer not being able to identify the student or the group to which he belongs.

It is anticipated that the use of the design and/or approach, data collection strategies and data analysis strategies may assist to answer the research question and the sub-questions.

3.9 Ethical considerations

Approval from the Faculty of Education's Ethics Committee was obtained before the commencement of data collection. Firstly, an application form was completed and sent for approval to the Ethics Committee. The application form illustrated all the safeguards against physical, psychological, social, legal harm and human rights violation of the participants (Sieber, 1998). The application form contained the following information:

- *A short summary of the study.*

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- *All first-year physics students are obliged to do all the laboratory practical activities as they form part of the physics course.*
- *All students are obliged to complete feedback forms for the department.*
- *The Department of Physics is responsible for the implementation of the ERGI laboratory practical activities and the names and contact details of researchers involved as well as the details of the head of department.*
- *The researcher is a postgraduate student in the Physics Department and may communicate with lecturers managing the implementation of inquiry in laboratory practical activities.*
- *Risk of potential harm to students will be minimised as laboratory assistants were trained to provide continuous guidance to both the control and experimental groups as needed.*
- *A researcher will monitor the experiment, and, if cause for concern is raised, action will be taken to correct the issue.*
- *Participants are allowed to leave the study on written request, with their results being withdrawn from the study.*
- *Students, consented to participate in the study, would be randomly assigned to either the control or experimental group.*
- *Students, who did not consent, would do the traditional laboratory practical activities.*

In addition, permission was asked from:

- *The Department of Physics to perform the study and use their names in the research study.*
- *The lecturer responsible for teaching the course.*
- *A subgroup of students who participated in focus group interviews.*

Students who agreed to participate in the focus groups interviews were not compensated, but were provided with light refreshments.

At the start of the semester, students were formally briefed about the decision of the Department of Physics within the Faculty of Natural and Agricultural Sciences to redesign the recipe-based physics laboratory practical activities to inquiry-based format. Students were invited to participate in the study and informed that participation was voluntarily. In addition, students were informed that those who gave their permission to participate in the study would be systematically assigned to experimental and control groups.

Moreover, students were informed that they could withdraw from the study at any time when they felt like it. Students were required to consent that their activities (e.g. laboratory worksheets, combined practical examination and theoretical year-end examination marks) in the laboratory course could be used as data in the study. Students that did not consent would do traditional recipe-based practical activities. Students were then handed two copies of the

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consent form (one for their own reference and one to complete and sign). All students were 18 years or older, therefore there was no need to obtain signatures from parents or guardians.

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Chapter 4: Results

In this chapter, the results gathered, using the open-ended questionnaire (VNOS Form-C), FGI, and the performance in the combined practical examination and theoretical course are discussed. In Section 4.1, the focus is on the qualitative analysis of the responses to the VNOS questionnaire and the FGI. In Section 4.2, the quantitative analysis of the responses to the VNOS questionnaire will be presented. In addition, in Section 4.2.2 the gender differences in understanding of the seven aspects of NOS are discussed. This is followed by the discussion in Section 4.2.3 of the extent to which the academically high and low achieving students differ in their understanding of NOS. In Section 4.3 the students' attitudes and beliefs relating to the practical course as reflected in their responses during the FGI are discussed. In Section 4.4, the effect of ERGI laboratory practical activities on academic performance of students is presented. In Section 4.4.1 the academic performance of the control and experimental groups in the practical and theoretical sections of the course will be analysed and compared. The data would be further analysed in terms of high and low achieving students in Section 4.4.2. In the last Section 4.5, the chapter summary is presented and addresses students' understanding of the nature of science (Section 4.5.1), students' views on the practical course (Section 4.5.2) and their academic performance (Section 4.5.3).

4.1 NOS: Evaluation of students' understanding

In this section an analysis of the students' understanding of NOS is presented. This scoring of the VNOS questionnaire was done blindly to eliminate any possible bias towards either of the two groups. Similarly, the results are reported here without making a distinction between the control and the experimental groups. The aim of this section is to provide a general overview of the understanding of different NOS aspects by the entire sample of students used in the current study and to illustrate and justify the scoring procedure. Typically, the answers in the control and experimental groups were not different enough to justify a comparison at this level.

The numbering system, for example, V9, represents the names of participants who took part in the VNOS test and interviews in the current study. The scoring process of the VNOS is discussed and illustrated by informative examples of students' responses. Ideas emerging from the written responses to the VNOS questionnaire and the ERQs as well as from the FGI are discussed. Each aspect of NOS is discussed separately.

In this section answers given by the students to the ERQs at the end of each practical as well as the answers given during the VNOS-C questionnaire and FGI, that were held at the end of the practical course, are discussed.

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4.1.1 Tentative aspect (TN)

At the end of the practical course, 40% of the sample demonstrated informed views of TN. In fact, the majority of students expressed the informed view that science is tentative in nature and that changes may occur due to technological advancement (23%), modern methods of experimentation (29%) and expansion of scientific knowledge (15%). However, the view that scientific knowledge may change as a result of revolution or evolution of ideas was not expressed at all. Furthermore, they used key terms that were discussed during the course, such as "evolve", "advances," and "progresses" to express their informed views. Here are few typical examples from the post-questionnaire and interviews with certain students:

> *V8 (VNOS q.4): "Scientific theories do change. As we gain more data and information on specific topics our explanation of them changes to better explain the data. Scientific theories provide the best possible explanation of the universe at the time. Many times it is possible to derive many relationships between properties without truly being able to explain the actual property, for example a lot of good work was done in electricity before positive and negative charges were understood." (Informed)*

> *V44 (VNOS q.4): "Theories develop and change continuously as our understanding and technological capabilities evolve. We learn theories in order to learn what currently exists, find the flaws and/or contradictions and strive to build new theories to better the existing ones, e.g. is Einstein bettering Newton's theory of gravity. Two separate theories have helped us to describe gravity has improved." (Informed)*

During the FGI a certain student, V23 when responding to FGI q.6 expressed an informed view relating to TN.

> *V23 (FGI q.6): "Science is not like constant. Because you know this theory for like years and then after few years the theory changed based on the new observations from new practicals which are being performed. And science is universal, I can say that because the science we are studying now, like if you can actually do follow ups about scientists and all of those things, they are from other countries and even the other continents." (Informed)*

Many students also expressed their informed views that science knowledge may change in the VNOS q.6 addressing the atomic model. For instance, half the sample after the course demonstrated informed understanding that researchers are not sure of the atomic model and that it might change in the light of further discoveries. This suggests that students believe that scientific theories are not certain but unstable. Here are some examples of post course informed views for the atomic model:

> *V8 (FGI q.6) "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." (Informed)*

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V9 (FGI q.6): "Scientists cannot directly observe atoms in the sense of our everyday lives. We discover more about the structure of atoms by how they interact with other particles. These experiments can give us a better idea of atomic structure." (Informed)

V68 (FGI q.6)*: Scientists are fairly certain based on conclusion from experiments done, but it is very hard for scientists to track the base particles in such an experiment, since they are so small. As their knowledge has expanded we have also determined that an atom is not the smallest particle of matter. (Informed)*

Student V8 gave similar answers in the questionnaire and interviews enhancing reliability of students' answers and trustworthiness of results. Almost half of the students (41% of the sample) at the end of the practical course expressed naive views as shown below:

V30 (VNOS q.4): "I think that they do not change because different scientists may have different views on the theory so there will not be a concrete knowledge about the topic. We learn theories in order for us to understand the way the world works, especially nature we have to be well informed and we do so by learning scientific theories." (Naïve)

Naïve views regarding the scientists' level of certainty about the atomic structure, i.e. believing that it will not change, included:

V20 (VNOS q.6): "They obviously have to be very certain of the structure of the atom otherwise they would not tell the world and make it official that it has that structure". (Naïve)

V39 (VNOS q.6): "Scientists are pretty much certain about the structure of the atom since experiments have been done in order to determine what the structure looks like. They have equipment that is able to magnify material a billion times to come up with what looks like the shape." (Naïve)

Approximately 19 % of the sample had mixed views on atomic structure after the course:

V65 (VNOS q.6): "Scientists are rather certain, evidence of mass and charge of particles were used. Also electrons do not orbit in a fixed path". (Mixed)

V66 (VNOS q.6):"In that point of view it is still investigated further as to how accurate this representation can be, but since it is applicable on magnetic field, electric field, chemical reaction using that representation it can be regarded as certain until new discoveries are made." (Mixed)

4.1.2 Empirical nature (EN)

At the end of the practical course, 67% of the sample expressed the view that scientific knowledge requires justification in the form of experimental evidence generated through scientific experiments and investigations. These students demonstrated an informed view that scientific experiments are not the only way but, rather, that there are other means such as

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observations and investigations of generating scientific knowledge. Moreover, students used key terms that were discussed during the course, such as "procedure," "test," "observation of natural phenomena", and "evidence/results" to express their informed views. Here are few typical examples of informed views from the post-questionnaire with certain students:

> *V13 (VNOS q.3): "Yes experiments are performed in order to validate scientific knowledge. Some knowledge can only be quantified through physical interaction and computation, and the element of unanticipated events can only occur through experiments. We can only think so far before we need to believe and validate what we have thought to acquire." (Informed)*

> *V17 (VNOS q.3):"Yes if scientific knowledge was not backed up by experiment then we would never be sure that each knowledge holds. An example is Ohm's law if he had not done the experiments he would not have been able to conclude his law." (Naïve)*

> *V28 (VNOS q.3): "Yes to form a theory or a law there should be a lot of experiments to show that the hypothesis holds under a lot of trials. Evolution, for example, could only be accepted as a theory when there were sufficient researches done on the topic to confirm it." (Informed)*

The sentiments expressed by V13 and V28 were rare among other students. Many students showed naïve views regarding the fact that scientific theories may or may not be developed based on experiments only. The sentiment expressed by V17 above, i.e. that experimentation is the only source of empirical evidence, was very prevalent among the other students too. Scientific knowledge may not be developed through controlled experiments only but it may be generated through other means such as observation of the natural phenomena and investigations. However, for a theory to be considered a scientific theory, it should be supported by empirical evidence. Here are some examples of how students experience that scientific theories learnt in class relate to content of the performed practical activities from the FGI:

> *V23 (FGI q.1): "Okay, basically the practical activities were fine not difficult but they actually exposed us to variety of physics things that we did not know about before. Like, the apparatus we were using during the practicals and some other physics concepts that we actually learnt in class. But we didn't know how to apply, we were actually given chance to actually see the application of those physics concepts during the practicals. Like for example, connecting those circuits, ja. We only knew how to draw the circuit diagrams but we didn't actually know how to connect what materials until we do the physics practicals."(Informed)*

> *V49 (FGI q.1): "I think that, the thing is, it really made it easier to relate to the theory and the fact that practical did not take that much preparation. I think that was nice because the thing is like we do not have time to spend hours and hours to prepare for something. And then the fact that usually we were preparing for an hour may be for the practicals and it was not that hard. You can actually like see how everything is coming together. You can see the full picture when doing the practicals, because they made it easier to understand the topic and they made it easier to write test because like if you forgot something, you can think ohh what*

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> *did we do in a practical and you could actually make a comeback from that." (Informed)*

These two quotes addressing FGI q.1 reflect the students' general understanding that the practical activities that were conducted prior to lectures addressing the same physics topics assisted them in understanding the physics content better. Practical activities also enabled students to understand the real application of physics concepts learnt in class.

> *V13 (FGI q.2): "I think the one where you investigate on your own (they all seem to agree).If you are given guidelines then it will be more of doing theory work where you are just confirming it. Whereas when you are investigating on your own you could discover things for your own and is usually your own discoveries are remembered more because they are more important to you, because you discovered them on your own instead of doing someone' s work." (Informed)*

> *V23 (FGI q.2): "Okay, I would say, I would prefer, aaa... to investigate on my own, so that I figure out things on my own. Because when you are guided you just follow the procedure but then at the end of the day you acquire less knowledge than when you do things on your own and see what is going on, like individually." (Informed)*

The above two quotes, relating to students' preference on the type of practical activities (FGI q.2), demonstrate that many students prefer practical activities where they have control in the development of scientific knowledge rather than the ones that direct students what and what not to do. Practical activities that promote individual independence also encourage students to think for themselves and students are highly unlikely to forget what they have discovered by themselves.

At the end of the practical course, 10% of the sample demonstrated a naive view of EN.

> *V5 (VNOS q.3): "I believe that the development of scientific knowledge has indeed required experiments. If no experiments were done in order to test scientific theories most if not all of the scientific theories would still be theories. There will not be any satisfying degree of certainty, and it will thus very difficult to develop scientific knowledge." (Naïve)*

> *V7 (VNOS q.3): "Yes, one cannot find out how the universe works by theory alone and thus experiments must be performed to make sure those theories are more than good ideas, for example, the experiments on gravity helped us learn more about it and changed the whole scientific view of the universe." (Naïve)*

Lastly, 23% of the sample had mixed views at the end of the practical course.

> *V10 (VNOS q.3): "Yes as scientific knowledge is proven knowledge, it cannot be proven without experimentation. Even observations are a type of experiment." (Mixed)*

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V22 (VNOS q.3): "Yes scientific knowledge is not the same as general knowledge, so in order to develop scientific knowledge, some test must be done to show the proof of the knowledge." (Mixed)

4.1.3 Theory vs. law (TL)

During the practical course, many students demonstrated mixed views regarding the fact that laws and theories are distinct types of knowledge, but rather regarded it as types of knowledge that is hierarchical arranged, related as follows:

V8 (ERQ q.2): "A law is a mathematical relationship that can be tested or obtained from empirical data. A theory is a description of how things work together, to give a mathematical relationship. Theory can also be confirmed by experiments." (Mixed)

V9 (ERQ q.2): "Laws are related to knowledge of how something behaves, perhaps ideally, under certain conditions. Theories give us the knowledge to explain why these laws hold." (Mixed)

V15 (ERQ q.2): "Laws relate to theories because they are the real world applications of the ideas explored in scientific theories. Coulomb's law and the theory of electromagnetism is an example of how a law is related to a theory." (Mixed)

In all three quotations, it appears that the type of knowledge located at the top of the hierarchy, irrespective of whether it is a law or a theory, is regarded as an absolute fact. Many students described "truth" as being either a law or theory that is justified by experimental evidence or controlled experiments. In total, after the practical course 18% of the sample still expressed mixed views regarding TL. Moreover, after the practical course 15% of the sample demonstrated the informed view that theories and laws were distinct forms of knowledge. This new perception is represented in the following students' responses:

V8 (VNOS q.5): "A scientific theory is the best explanation of observed phenomena, such as the atomic theory. A law describes the relationship between physical properties for example the Newton's law of gravitation." (Informed)

V9 (VNOS q.5): "Yes laws are statements regarding certain properties of theories, e.g. the theory of electromagnetism comprises many laws, such as Faraday's law of induction." (Informed)

Student V8 provided similar responses during the practical course and after the post-test, confirming the reliability of the students' answers and the trustworthiness of results.

At the end of a practical course, 67% of the sample still demonstrated naïve views regarding the distinction between theory and law, for example:

V7 (VNOS q.5): "A scientific law is a theory that has massive amounts of evidence supporting it which makes it almost certainly how the universe works for

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example Newton's law of motion have so much evidence supporting it that it pretty much is how things move."(Naive)

V15 (VNOS q.5): "Yes, theories are just that, unproven ideas while laws are theories that have been proven in almost all cases to be true." (Naive)

V22 (VNOS q.5): "Yes there is - scientific theory can become a scientific law, and is an explanation of an observed phenomenon. Scientific law are typically applied to a specific discipline such as biology, chemistry and physics."(Naive)

4.1.4 Observations vs. inferences (OI)

At the end of the practical course, 40% of the sample demonstrated informed views of OI. When responding to VNOS question 8, addressing the extinction of the dinosaurs, several students expressed the informed view that different conclusions may be reached from the same observations of a single phenomenon due to scientists' different expertise in their fields of research (27%), scientists' different capabilities in imagination and creativity (4%), different individual experiences guided by their social and cultural values (19%). The students' perceptions are exemplified by the following citations from the post-questionnaire:

V8 (VNOS q.8): "The data does not give a lot of information and leaves itself open to a lot of interpretation which will be significantly influenced by a person's own thoughts and beliefs." (Informed)

V9 (VNOS q.8): The interpretation of data is different possibly due to different external research conducted by each group that gave them the idea that the data might support these other pieces of evidence. (Informed)

V34 (VNOS q.8): "The interpretation of data is somewhat subjective and in most case selectively- captured in order to support the already existing ideal within the community of scientists that share it." (Informed)

Conversely, 45% of the sample after the practical course demonstrated naïve views of OI. These students still believed that the two suggested events (i.e. a huge meteorite striking the earth or a huge and violent volcanic eruption) are the main causes of the dinosaurs' extinction. Typical views expressed by the students in the post-test are the following:

V10 (VNOS q.8): "Because the data is from so many years ago it is a fact that some great heat source caused the extinction of the dinosaurs but the source of heat could be either". (Naïve)

V14 (VNOS q.8): "Both would have led to the same result. Namely, all the dust and smoke etc. would have blocked out all the sun for a long period of time causing extinction."(Naïve)

V25 (VNOS q.8): "Both scenarios create huge clouds of ash that block out the sun and stop plant growth and kill off herbivores which kill off carnivores which then they will be extinct." (Naïve)

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One possible explanation may be that these students have the view that inference is the direct understanding of what they observe. If they subsequently give an interpretation of what they see, then their understanding would be the only possible correct answer, since it reflects what they see. In addition, 15% of the sample had mixed views:

> *V51 (VNOS q.8): "Different conclusions are possible because theories are made through data. Until theories are proven and can be certified as a law, different theories are possible." (Mixed)*

> *V65 (VNOS q.8): "Certain events can have the same type of after effects. The scientists can have different theories that produce the same result." (Mixed)*

4.1.5 Imagination and creativity (IC)

During the practical course, a total of 31% of the sample demonstrated informed views of IC. These included 19% of the sample that demonstrated an informed view that IC is used mainly during the analysis, interpretation of data and drawing of conclusions, 3% of the sample that demonstrated an informed view that IC may also be used during the building up of different models, and 9% of the sample that explained that scientists use IC but they did not specify the stage where imagination and creativity are used.

> *V9 (ERQ q.1): "Yes sometimes the interpretation of data requires a completely new approach. In some experiments, data may contradict current theories as has happened many times in the past, therefore new and creative thinking is needed always." (Informed)*

> *V65 (ERQ q.1): "Yes, imagination and creativity is necessary for scientists to build models to describe different situations and to invert new theories to describe the world around us." (Informed)*

In addition, during the practical course about half of the sample had a naïve view of IC. These students did not believe that scientists use IC at all. They expressed the following views during the practical session:

> *V8 (ERQ q.1): "No scientists have to handle data according to maths and physics principles. But they do often use intelligent imagination and intuition to find physical relationships that exist among data." (Naïve)*

> *V15 (ERQ q.1): "No the data obtained from experiments is factual, scientists do not use imagination and creativity to draw conclusions from the data. The experiments are usually accurate and precisely carried out to ensure factual data." (Naïve)*

> *V17 (ERQ q.1): "No I believe scientists try to best measure and collect accurate data and make a conclusion based on that data. Wrongful conclusions are drawn because the data was not accurate and not because of how creative and imaginative one is." (Naïve)*

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At the end of the practical course, only a few of the students (25%) demonstrated informed views that scientists use IC in all stages of their research (see Table 4.1). This new perception is exemplified in the following students' answers:

> *V3 (VNOS q.10): "Yes because imagination and creativity must be used to come to a conclusion and to understand science. (i) Planning is needed when you do experiments to make sure you get the right results as well as data collection. And conclusion and result must be added" (Informed)*

> *V5 (VNOS q.10): "I think that scientists use imagination and creativity in all three stages. Using their creativity and imagination in stages (i) and (ii) will improve and optimise the experiment and the data collected, and in stage (iii) will help the scientists to envision and better illustrate their findings." (Informed)*

> *V13 (VNOS q.10): "Scientists used creativity and imagination in all 3 stages. In the development of scientific equipment, in the different manners in which an experiment can be conducted, and the interpretation of results and further questions that can arise from them. Imagine quantifying the size of the universe, the sight of nebulas, the form of an atom, and the idea of how charges flow in a circuit." (Informed)*

These students further demonstrated an informed view that the IC used during the development of existing theories may also be used to enhance our knowledge. At the end of the practical course, 53% of the sample demonstrated mixed views regarding the stages where IC may be appropriately used, these are: stage (i) (planning and designing experiments) and stage (iii) (data analysis) (VNOS q.10). These students further demonstrated mixed views by indicating that data the collection stage does not involve IC. Many students did not provide examples for their ideas:

> *V7 (VNOS q.10): "Scientists use imagination and creativity to get over design problems (one cannot see electrons with an eye), data collection (how can electrons be measured in a copper wire) and in conclusion (data is numbers and will not say what it means)." (Mixed)*

> *V8 (VNOS q.10): "In planning and design they most use their imagination and creativity to know how they will be able to carry out the observations. After data collection they must use their imagination to fit it into other information." (Mixed)*

> *V40 (VNOS q.10): "Creativity is used during the planning and design stage. Possibly imagination may be used with results and explanation of the data." (Mixed)*

The remaining 22% of the sample demonstrated naïve views of IC as shown by the following quote:

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V6 (VNOS q.10): "No, imagination and creativity can't be used in explaining results. The reason being that this would make science subjective and not objective. For example, when magnetic fields were first discovered it is better to say that we don't know or understand, then to use imagination and say that it uses magic to communicate." (Naïve)

4.1.6 Social and cultural values (SC)

During the practical course, approximately half of the sample demonstrated informed views that science is universal but is influenced by SC. These students advanced various reasons that science knowledge is influenced by SC due to cultural beliefs (29%), religious beliefs (7%), different thinking capabilities (3%), technological advancement (3%) and different scientific methods (2%). Additionally, 8% of the sample expressed the view that science is influenced by SC without advancing reasons. During the practical course the students stated the following informed views:

V8 (ERQ q.5): "Yes scientific evidence is most often interpreted according to the cultural and philosophical values of those who are interpreting it. It can often take a long time for evidence to dislodge the cultural perspective." (Informed)

V9 (ERQ q.5): "Yes, early scientists seemed to try and reconcile science with religion and it was often frowned upon if the science did not reconcile. This influenced the advancement of science in some places and required radical non-conformers to break the dogma surrounding new scientific knowledge." (Informed)

V43 (ERQ q.5): "Science is the study of nature, and since a person's way of thinking is influenced by their surroundings and cultural values, the way they perceive and interpret several natural elements will also be influenced by social and cultural values of the environment. For example, Isaac Newton would not have studied gravity if his environment had no apple trees." (Informed)

During the practical course, very few students expressed mixed views regarding SC.

V14 (ERQ q.5): "I do not think that the solid facts are influenced but I think that the way in which it is understood and interpreted can be influenced." (Mixed)

V28 (ERQ q.5): "Science is not influenced by social and cultural values, but the interpretation of science is influenced by social and cultural values." (Mixed)

V30 (ERQ q.5): "No I do not think that scientific knowledge is influenced by social and cultural values because an environment keeps changing due to pollution and natural hazards therefore the scientific knowledge would also not be stable and it will not be certain." (Mixed)

Similarly, after the practical course, 11% of the sample showed mixed views on SC.

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V10 (VNOS q.9): "Science is universal because it is constant and the same rules apply everywhere. Social and cultural structures only determine the rate at which science develops. It develops universally the same. For example, Newton developed calculus but at the same time someone else (I can't remember the name) also developed calculus in another part of the world". (Mixed)

V35 (VNOS q.9): "We are social beings thus science can never truly be free of human thought and how human thought has been shaped but science tends to limit this influence" (Mixed)

After the practical course a few students (12%) demonstrated informed views regarding SC:

V1 (VNOS q.9): "During history many scientific discoveries were fuelled by cultural and scientific norms such as chemists which experimented to produce gold. Science is both but becoming more universal. Modern science is more universal since evidence is easily shared worldwide and also easily peer reviewed." (Informed)

V8 (VNOS q.9): "Science is influenced by social norms and values because of the evidence are inconclusive and scientists drawing conclusions cannot escape from their own assumptions and beliefs. For example, many scientists hold to evolution even though the evidence is not conclusive, because their perspectives cannot allow them to admit the other alternatives." (Informed)

Other students demonstrated informed views that scientists are human and thus science is influenced by their individual beliefs shaped by their cultures, however, they did not advance examples of such influences.

In addition, after the practical course, 77% of the sample demonstrated naïve views that science knowledge is not influenced by SC. This perception is exemplified in the following student's answer:

V48 (VNOS q.9): "Science does not reflect social and cultural values and it is based on the laws and theories. Science is universal because it is done all over the world." (Naïve)

V61 (VNOS q.9): "Science does not change based on where it is practiced. It is universal because natural interactions are universal, not culture-based." (Naïve)

The sentiments expressed by students V48 and V61 above, were prevalent amongst the students. Some students also expressed their views concerning the TN that are linked to the SC aspect of NOS. In response to the VNOS q.9 (addressing the role of SC) only 7% of the sample demonstrated informed views that although SC influences scientific knowledge it may also cause science knowledge to change. These students demonstrated an informed view that integrates SC and TN in bringing about change in science knowledge due to different thinking capabilities (3%), technological advancement (3%) and different scientific methods (1%). For example, here are some typical post course informed views for the SC question:

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V40 (VNOS q.9):" Yes, cultural values are used to grow up children and these values are imprinted at young age as they grow up and this can certainly affect the way a person thinks about everything in life." (Informed)

V45 (VNOS q.9): "Yes, because science is interpreted in a variety of ways according to the level of how modernised certain environments are in terms of technology. So technology aggravates the scientific knowledge different environments attain."(Informed)

Students' responses to this VNOS q.9 also demonstrated informed views of the tentativeness issue, seeing science being affected by SC. They also viewed scientific knowledge as tentative as it may also be influenced by culture and society. After the practical course, 77% of the sample demonstrated naïve views that science is not influenced by SC since scientific theories and laws are considered as absolute knowledge. This demonstrates that the practical course had a small effect on students' understanding of SC as these typical examples from the post-test show:

V9 (VNOS q.9):" Science is the study of the natural universe and does not change based on culture. Science does not care who practices it, the passion for curiosity and nature is all that is needed. For example, the largest physics experiment in the world is supported by a diverse pool of nations working together to understand the universe. That is universal." (Naïve)

V14 (VNOS q.9): "Science is practiced all over and has been for a very long time, and there have been numerous occasions where the same discovery/theory was made in different parts of the world at the same time. This shows that science is universal. Science is not based on made up stuff, it is based on plausible theories and discoveries that can be proven." (Naïve)

V43 (VNOS q.9): "Science is not biased, it clearly states the facts without favouring a specific group, anyone anywhere can study science and it works with results and creates findings that make it. Science in Asia is the same as science in Africa, regardless of the cultural differences the same experiments, could be conducted in both continents." (Naïve)

These three quotes demonstrate naïve views by 77% of the sample that science may not be affected by SC. This finding suggests that for these students scientific theories and laws which are diverse kinds of scientific knowledge may never change and that change in science is not essential.

The differences between quotes obtained during and after the practical course indicate a remarkable difference in students' views regarding the absolute universality and objectivity of scientific knowledge. However, this does not demonstrate an informed view of what SC entails. Although students earlier displayed a better understanding of SC, they could not translate that understanding into realising the influence of SC in the development of scientific knowledge. Firstly, after the practical course, many students provided examples of cultural and social influences different from those which they discussed during the practical course. Secondly, after the practical course, quotations by students show that they acknowledge that

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SC influence may occur. This suggests that the views of the students have changed over the duration of the practical course.

4.1.7 Scientific method (SM)

During the practical course, less than half (40%) of the sample demonstrated informed views that scientists use a multiple of scientific methods. However, the reasons advanced by the students did not show an informed view of what the use of a single universal method involves. For instance, from the 40% of the sample 31% demonstrated a mixed view that different scientific methods are used to either prove that scientific knowledge is accurate or to broaden scientists' knowledge base. In addition, from the 40% of the sample, 9% demonstrated a mixed view that the use of different methods by scientists may lead to the same results. These views were prevalent in many students. The students stated the following:

> *V11 (ERQ q.6): "No they all use different methods to come to the same conclusions because everyone uses his/her method in different ways." (Mixed)*

> *V18 (ERQ q.6): "No because different scientific methods can arrive at the same results and this can show the interrelationships between scientific methods and bringing about better developed scientific knowledge." (Mixed)*

The other reasons supporting informed views conveyed by students for using different scientific methods were that scientists have different thinking abilities, individual preferences or that they were guided by experiences in their respective research fields. These views were expressed by 9% of the sample as shown in the following extracts:

> *V26 (ERQ q.6): "No they use different methods according to their different ways of thinking and analysing their practical notes or other scientific practical notes." (Informed)*

> *V31 (ERQ q.6): "No every scientists has a preference towards different scientific methods, they choose different methods depending on the task at hand and personal preference." (Informed)*

> *V47 (ERQ q.6): "Scientists use different scientific methods that work with them best or suit their working style and then the scientists may convert their findings to one general/ standard scientific conclusion that is accepted by all the scientists." (Informed)*

At the end of the practical course, a small number of students (14%) demonstrated informed views regarding the use of different scientific methods by scientists guided by their individual experiences or observations, different levels of imagination and creativity and different expertise in their fields of research.

> *V8 (VNOS q.3): "In many cases the development of scientific knowledge does require experiments, for example the caloric theory of heat was disapproved by the use of experiments and our knowledge of electricity and magnetism was*

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gained through experiments. However Kepler formulated his laws of planetary motion using carefully recorded observation of the planets. Generally, the development of scientific knowledge does require experiments." (Informed)

V13 (VNOS q.3): "Yes experiments are performed in order to validate scientific knowledge. Some knowledge can only be quantified through physical interaction and computation, and the element of unanticipated events can only occur through experiments. We can only think so far before we need to believe and validate what we have thought to acquire." (Informed)

V41 (VNOS q.3): "It is possible to derive different conclusions as each idea might have followed a different path. Many things in science have the same characteristics but one could conclude different results." (Informed)

After the practical course, 68% of the sample expressed mixed views regarding SM as these typical quotes from the post-test show:

V15 (VNOS q.3): "Yes certain theories can be developed and thought to be true but they need to be tested through experimentation to be proven as fact. Scientific knowledge could not develop until the theory of gravity was proven". (Mixed)

V45 (VNOS q.3): "Yes because a lot of scientific knowledge is based on actually performing certain experiments to prove that it is indeed the correct knowledge. For example Ohm's law, it is a law which had to be proved and still continually being proven by experiments to prove that it is correct." (Mixed)

V60 (VNOS q.3): "Yes it requires experiments because it gives both the practical and the theory part for the development of scientific knowledge." (Mixed)

Lastly, at the end of the practical course, 18% of the sample demonstrated naïve views of SM.

V7 (VNOS q.3): "Yes, one cannot find out how the universe works by theory alone and thus experiments must be performed to make sure those theories are more than good ideas, for example, the experiments on gravity helped us learn more about it and changed the whole scientific view of the universe." (Naïve)

V36 (VNOS q.3): "Yes science has to have a valid reason or proof thus any scientific developments have to be proven to be true and not just opinions of a certain individual for example you cannot say that the force of gravity doesn't exist you have to show proof of how that statement is true." (Naïve)

4.2 Nature of Science: Quantitative results

In this section the results from the VNOS-form C questionnaire, administered after completion of the practical course to all participants in the study, are discussed. The reader is reminded that the students did not write a pre-test. The students were assigned systematically

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to the groups by assigning every second student on the alphabetical list to the experimental group and the rest to the control group. Therefore, the groups were assumed equivalent at the start of the study. The difference between the VNOS scores of the experimental and control groups will be ascribed to the effect of ERGI laboratory practical activities on students' understanding of NOS. Also, differences in the understanding of NOS will be explored, comparing male to female students as well as academically high to low achieving students.

4.2.1 Performance of the control and experimental groups in the VNOS test

Table 4.1 and Figure 4.1 show the percentage of students expressing informed, mixed and naïve views per VNOS aspect, for the control and experimental groups, respectively. Figure 4.2 shows the percentage of students with informed views per VNOS aspect for each group. From this, it can be seen that the understanding of the different aspects of NOS followed the same trend in both groups. The EN was well understood by both groups, and was by far the best understood NOS aspect. Reasonable understanding of two NOS aspects, i.e. TN and OI was demonstrated by both groups, while poor understanding of the aspects TL, IC, SC and SM was demonstrated by students in both groups.

Comparing the results for the control and experimental groups (see Figure 4.2), it is clear that the percentage of informed views in the experimental group was higher than the corresponding value in the control group, for each VNOS aspect. This indicates that the students in the experimental group benefited from the ERGI laboratory practical activities regarding all aspects of NOS, with overall 10 pp more informed views averaged across the 7 NOS aspects. A hypothesis test using the Fisher Exact Method for equality of the means of the two distributions yielded p = 0.008.

4.2.1.1 Tentative nature (TN)

Students in the experimental and control groups demonstrated a reasonable understanding of this aspect. In essence, 48% of the students in the experimental group and 32% from the control group demonstrated informed views of the tentative nature of science after completion of the practical course. There was a noticeable difference (16 pp) in the number of students expressing an informed view between the two groups (p = 0.178). These results show that the ERGI laboratory practical activities had a noticeable effect on students'

Table 4.1 Percentage of students expressing informed, mixed and naïve views in the control and experimental groups on each NOS aspect.

NOS	Informed (%)		Mixed (%)		Naïve (%)	
aspect	C	E	C	E	C	E
TN	32	48	49	33	19	20
EN	64	70	23	23	13	8
TL	8	22	13	24	80	54
OI	38	42	13	19	50	40
IC	18	33	65	42	18	26
SC	8	17	8	14	85	69
SM	10	19	66	70	24	12
Overall	25	35	34	32	41	33

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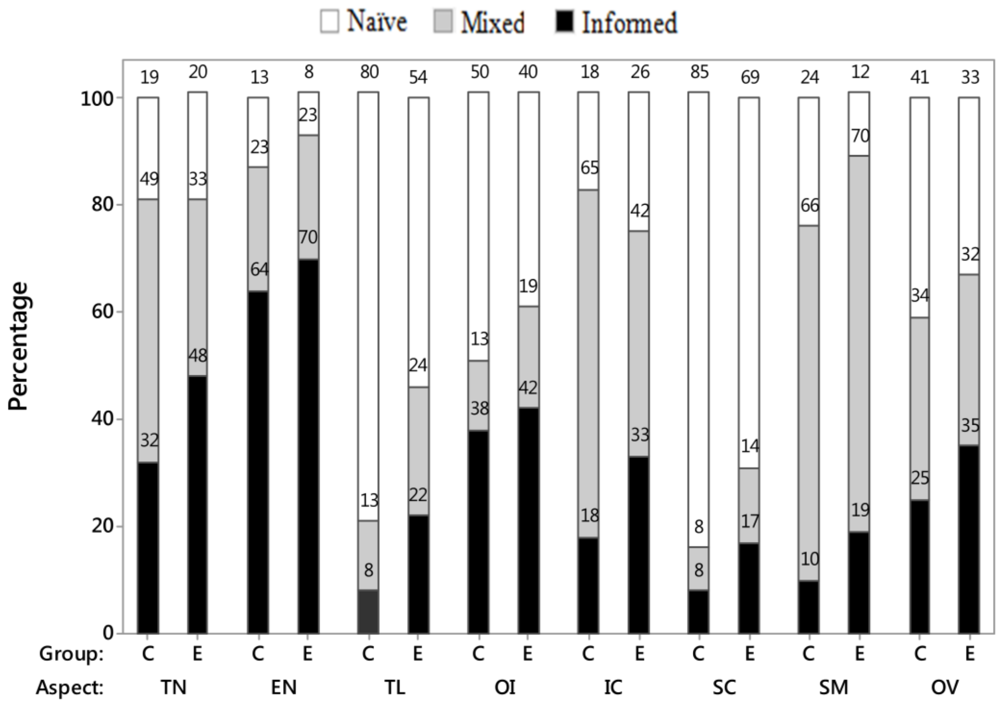

Figure 4.1 A stacked bar graph showing, for each NOS aspect, the percentage of students in the control group and the experimental group expressing informed, mixed and naïve views.

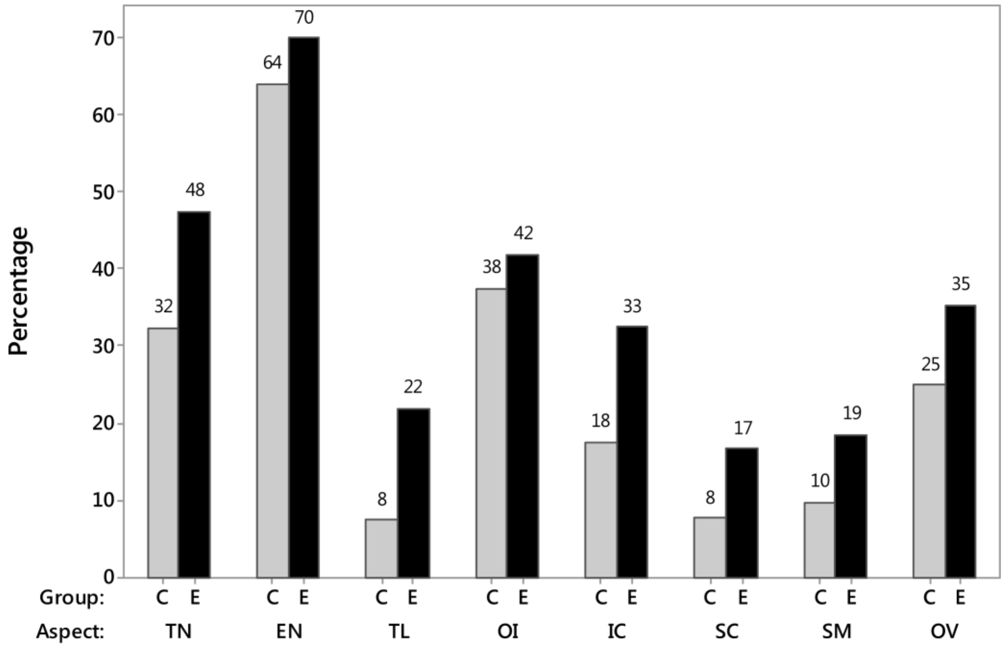

Figure 4.2 A bar graph of the percentage of students with informed views per NOS aspect in each group.

understanding that science knowledge may change upon the discovery of new empirical evidence, when compared to traditional practical activities.

In this study, the pre-test is not essential because the aim of this study was to determine the effect on students' understanding of NOS when replacing traditional practical activities with GI practical activities, where both groups received the same ERQs on NOS. The aim was to observe the relative advantage of one group to the other, so, assuming that the control group

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and the experimental group were equivalent at the start of the intervention, differences in the post-test may be ascribed to the difference in treatments of the two groups. A pre-test would therefore not give any more information on the possible reasons for the difference in performance of the two groups.

4.2.1.2 Empirical nature (EN)

Across the NOS spectrum, the EN was the best understood aspect for both groups. In fact, 70% from the experimental group and 64% of the students from the control group demonstrated informed views regarding the empirical nature of science after completion of the practical course. It was also the aspect in which the least number of students expressed a naïve view. There was a reasonable difference (6 pp) in the number of students expressing an informed view between the two groups (p = 0.577). These figures indicate that ERGI laboratory practical activities had a reasonable effect on students' understanding of EN when compared to traditional practical activities.

4.2.1.3 Theory vs. law (TL)

The two groups of students demonstrated a poor understanding of this aspect. Basically, only 22% of the students from the experimental group and 8% from the control group demonstrated informed views regarding TL after completion of the practical course. The large number of naïve views supported the claim that this aspect was poorly understood by both groups, as on average, 67% of all the participants had naïve views. There was a noticeable difference (14 pp) in the number of students who had an informed view between the experimental and control groups (p = 0.067). These figures suggested that ERGI laboratory practical activities had a noticeable effect on students' understanding of TL when compared to traditional practical activities. From this it could be deduced that the most significant effect of the ERGI laboratory practical activities on NOS understanding was in reducing the naïve views in the experimental group.

4.2.1.4 Observations vs. inferences (OI)

Students in both groups demonstrated a reasonable understanding of this aspect. Essentially, 42% of the students from the experimental group and 38% from the control group demonstrated informed views regarding the difference between OI after completion of the practical course. The large number of naïve views supported the claim that this aspect was not well understood by either group, as on average, 45% of the sample had naïve views. There was a small difference (4 pp) in the number of students who had an informed view between the experimental and control groups (p = 0.685). Correspondingly, the experimental group showed less naïve views than the control group by a difference of 10 pp. These figures showed that the ERGI laboratory practical activities had a small positive effect on students' understanding of OI when compared to traditional practical activities.

4.2.1.5 Imagination and creativity in scientific research (IC)

This aspect was poorly understood by students in the control group, with only 18% having informed views. The experimental group performed better, with 33% of the students demonstrating informed views regarding IC after completion of the practical course. There was a noticeable difference (15 pp) in the number of students having informed views between the experimental and control groups (p = 0.115). This indicated that the ERGI laboratory practical activities had a noticeable effect on students' understanding of IC when compared to

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traditional practical activities. The results from this NOS aspect showed an unusual feature, namely this was the only aspect in which the percentage of naïve views in the experimental group was greater than those in the control group. Though a difference of 8 pp is not that large, it is difficult to explain.

4.2.1.6 Social and cultural values in science (SC)

This was the poorest understood NOS aspect. Only 17% of the students from the experimental group and 8% from the control group demonstrated informed views regarding SC after completion of the practical course. This lack of understanding was emphasised by this category having the highest percentage of students having naïve views (85% control and 69% experimental). Despite the overall poor understanding, there was a reasonable difference (9 pp) in the number of students having an informed view between the two groups (p = 0.220). These figures illustrate that the ERGI laboratory practical activities had a reasonable effect on students' understanding of the SC when compared to traditional practical activities.

4.2.1.7 Scientific method (SM)

Both groups demonstrated poor understanding of this aspect. In effect, 25% of students from the experimental group and 19% from the control group demonstrated informed views regarding SM after completion of the practical course. There was a reasonable difference (6 pp) in the number of students having an informed view between the two groups (p = 0.247). These figures indicate that the ERGI laboratory practical activities had a small effect on students' understanding of using various scientific methods in science investigations when compared to traditional practical activities.

4.2.2 Relationship between the understanding of NOS and gender

The relationship between the understanding of NOS and gender was investigated by dividing both the control and experimental groups according to gender. The data were first analysed by comparing the differences between males and females in the control group. Overall, the females performed slightly better, however, in individual questions the results varied.

Hereafter, the gender differences in the control and experimental group were investigated to determine if the ERGI laboratory practical activities had a different effect on males than on females. The results showed that, although both the males and the females showed the same general trend, there were some questions where the effect differed between genders.

4.2.2.1 Differences in the understanding of NOS between males and females in the control group.

Table 4.2 and Figure 4.3 show the percentage of students expressing informed, mixed and naïve views per NOS aspect, comparing males (MC) and females (FC) in the control group. Figure 4.4 focuses on informed views only to present an overview of the gender differences found in the control group.

Comparing the results for males and females in the control group, it was clear that for a number of NOS aspects (TN, EN, OI, IC and SC) the females demonstrated a better understanding than males. The females outperformed the males for the EN (31 pp, p = 0.124), IC (6 pp, p =0.637), OI (4 pp, p = 1.000) and TN (1 pp, p = 1.000) aspects. The males had an

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Table 4.2 Percentage of male (MC) and female (FC) students expressing informed, mixed and naïve views per NOS aspect, in the control group.

NOS aspect	Informed (%)		Mixed (%)		Naïve (%)	
	MC	FC	MC	FC	MC	FC
TN	32	33	43	67	25	0
EN	58	89	26	11	16	0
TL	9	0	16	0	75	100
OI	36	40	15	10	49	50
IC	16	22	63	78	22	0
SC	7	13	3	25	90	63
SM	12	0	61	89	27	11
Overall	24	28	32	43	44	30

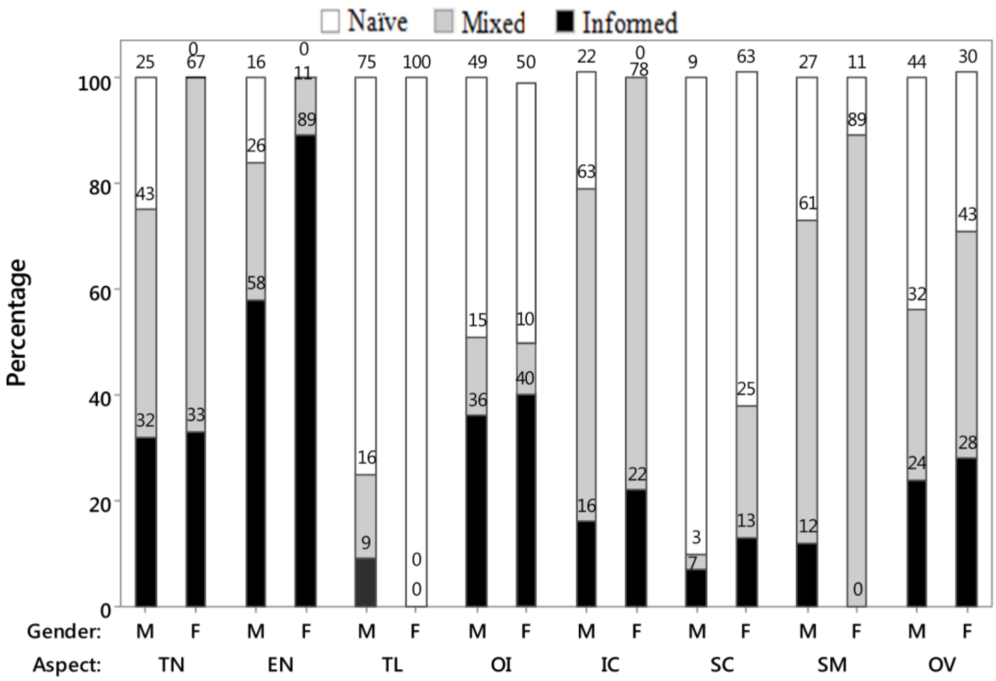

Figure 4.3 Percentage of males (M) and females (F) expressing informed, mixed and naïve views per NOS aspect, the control group.

advantage in the SM (12 pp, *p* = 0.561) and TL (9 pp, *p* = 1.000) aspects. The reasonably large differences between genders seem to be obscured by the overall score, in which females performed only slightly better (4 pp, *p* = 0.616).

4.2.2.2 Relationship between ERGI laboratory practical activities and understanding of NOS for males and females

Table 4.3 and Figure 4.5 show the percentage of students expressing informed, mixed and naïve views per VNOS aspect, for the males and females, respectively, in control and experimental groups after completion of the practical course. The data for the ME and FE groupings show all the salient features observed in the control group discussed earlier

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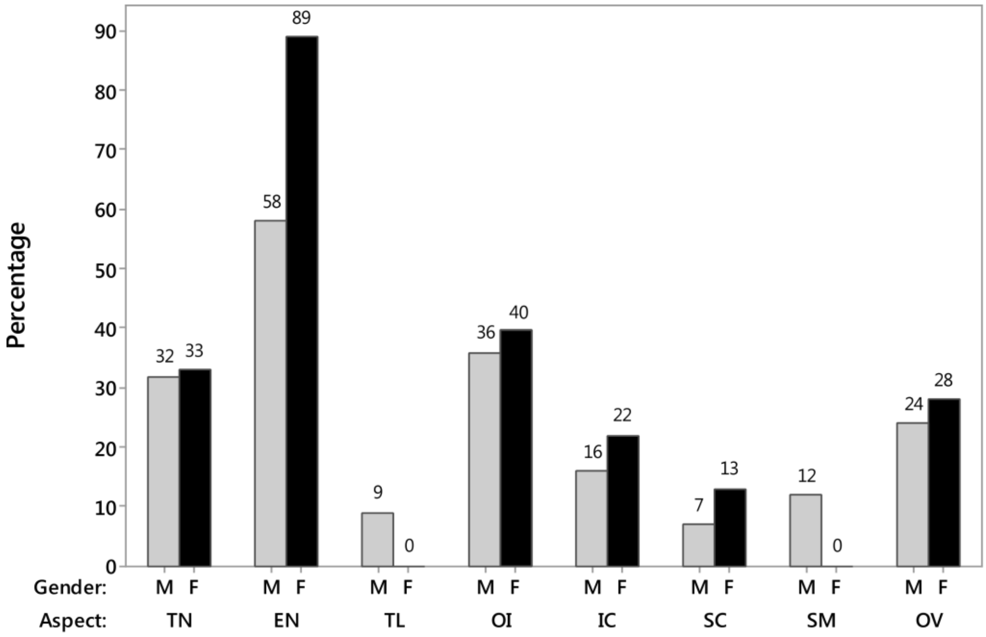

Figure 4.4 Percentage for males (M) and females (F) expressing informed views per NOS aspect, in the control group.

(Section 4.2.2.1), i.e. a good understanding of EN, a reasonable understanding of TN and OI and a poor understanding of TL, IC, SC and SM.

Comparing the results for the males and females in the control and experimental groups (see Table 4.3) respectively, it is clear that for all VNOS aspects the percentage of informed views for males in the experimental group (ME) was higher than those of the males in the control group (MC). The largest differences were for the TL (18 pp), SC (12 pp), SM (11 pp) and OI (8 pp) aspects. For females, this was also true for all aspects except EN and OI. For EN females performed significantly worse in the experimental group, however, for OI the difference was reasonably small (9 pp). This indicates that ERGI laboratory practical activities seem to generally benefit both males and females. The exception to the rule seemed to be EN and OI, where females seem to have been disadvantaged by the ERGI laboratory practical activities. Overall, it seems that the ERGI laboratory practical activities benefitted males more than females as there were 11% more informed views averaged across the 7 NOS

Table 4.3 Percentage of students expressing informed, mixed and naïve views per NOS aspect, for the males (M) and females (F) in control (C) and experimental (E) groups.

	Informed (%)				**Mixed (%)**				**Naïve (%)**			
NOS aspect	**MC**	**ME**	**FC**	**FE**	**MC**	**ME**	**FC**	**FE**	**MC**	**ME**	**FC**	**FE**
TN	32	45	33	55	43	38	67	18	25	17	0	27
EN	58	68	89	75	26	21	11	25	16	11	0	0
TL	9	27	0	17	16	20	0	33	75	53	100	50
OI	36	44	40	31	15	22	10	23	49	34	50	46
IC	16	24	22	50	63	52	78	25	22	24	0	25
SC	7	19	13	17	3	10	25	25	90	71	63	58
SM	12	23	0	8	61	63	89	85	27	13	11	8
Overall	24	35	28	35	32	32	43	34	44	32	30	31

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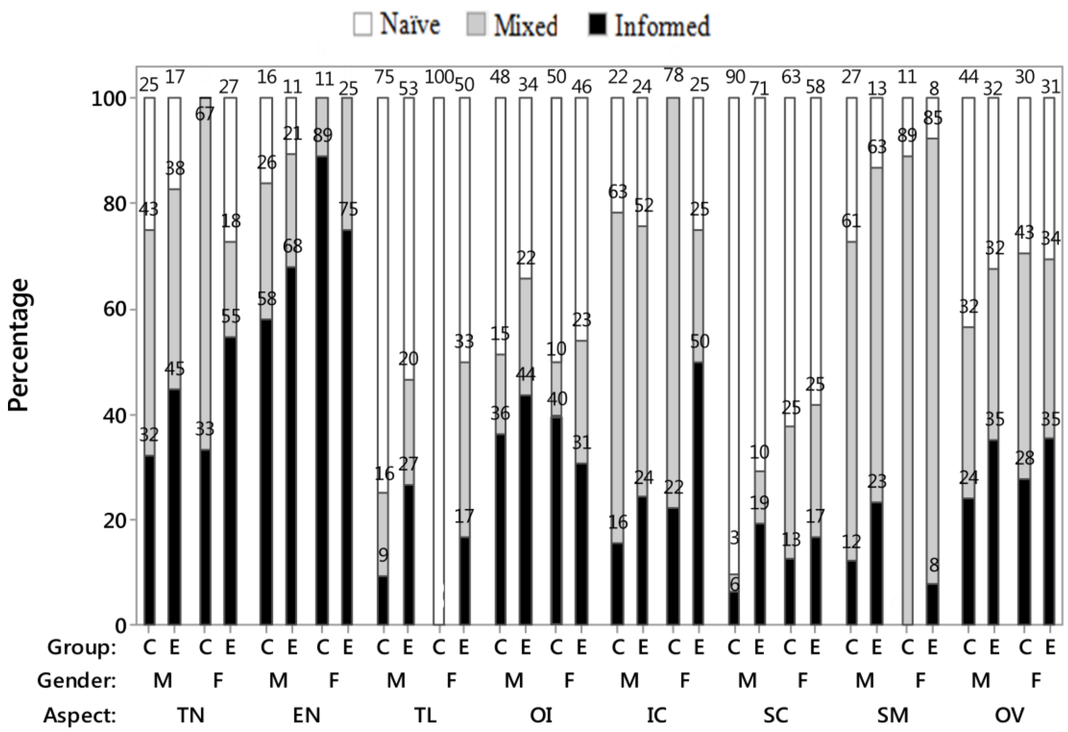

Figure 4.5 Percentage of males (M) and females (F) expressing informed, mixed and naïve views per NOS aspect, in the control (C) and experimental (E) groups.

aspects for males compared to 7% more for females.

4.2.2.2.1 Tentative nature of science (TN)

Males and females, in the control group, demonstrated a reasonable understanding of this aspect. In the control group, females outperformed males by a very small margin of 1 pp (32% males vs. 33% females' informed views) for this aspect.

For males, 45% of ME and 32% of MC showed informed views of TN (see Figure 4.5), i.e. a noticeable difference of 17 pp. On the other hand for females, 55% of FE and 33% of FC demonstrated informed views of TN, i.e. a large difference of 22 pp. Contrary to expectations, there was also a higher percentage of naïve views in the FE group, compared to the FC group, which is difficult to explain. From this it is concluded that both males and females benefited from ERGI laboratory practical activities as far as their understanding of TN is concerned, and that the benefit was stronger for female students.

4.2.2.2.2 Empirical nature of science (EN)

Across the NOS spectrum, the EN was the best understood aspect by males and females in the control group, with 58% of male and 89% of females in the control group having informed views. This aspect (together with IC and, to an extent, TN and SC) was the aspect where females significantly outperformed the males in the control group.

EN was exceptional, it was the aspect where females outperformed males significantly, while for IC, TN and SC the differences were much smaller. For instance, 68% of ME and 58% of MC showed informed views of the EN aspect of NOS. This indicates that the ERGI laboratory practical activities enhanced the number of informed views by 10 pp amongst

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male students. In contrast, for female students, the opposite trend was observed where 75% of FE and 89% of FC demonstrated informed views of this aspect. This indicates that the ERGI laboratory practical activities reduced the female advantage in EN, by improving the males and reducing females understanding.

4.2.2.2.3 Theory vs. law (TL)

Poor understanding of this aspect was shown by males and females in the control group. In the control group, males performed better than females by a reasonable margin of 9 pp (9% vs. 0% informed views) for this aspect.

For male students, only 27% of ME and 9% of MC showed informed views of TL, amounting to a noticeable difference (18 pp) in the number of informed views in the male experimental and control groups. The same trend was observed for females, where 17% of FE and 0% of FC demonstrated informed views of this aspect, amounting to a noticeable difference (17 pp) in the number of informed views between the female control and experimental groups. These differences indicate that, although both genders showed a poor understanding of this aspect, the ERGI laboratory practical activities had a noticeable effect on both males' and females' understanding of TL.

4.2.2.2.4 Observation vs. inference (OI)

Reasonable understanding of this aspect was demonstrated by males and females in the control group (36% males vs. 40% females had informed views). Females outperformed males by a small margin of 4%.

For male students, 44% of the experimental group (ME) and 36% of the control group (MC) showed informed views of OI, a reasonable difference of 8 pp. In contrast, the opposite trend was observed with females, with the 31% having informed views in the experimental group and 40% in the control group, which represents a reasonable margin of 9 pp. These figures demonstrate that the ERGI laboratory practical activities had a reasonable effect on males' understanding of OI and a reasonable negative effect on females' understanding of OI.

4.2.2.2.5 Imagination and creativity (IC)

Males and females showed a reasonably better understanding of this aspect (16% males and 22% females gave informed views), i.e. female students had a reasonably large understanding of 6 pp.

For male students, 24% of the experimental group (ME) and 16% of the control group (MC) showed informed views of IC, a reasonable difference of 8 pp. For females, 50% of the experimental group (FE) and 22% of the control group (FC) demonstrated informed views of this aspect, a large difference (28 pp) compared to the reasonable difference of only 8% for males. On the other hand, there was an anomaly in the naïve views where there were no students with naïve views in the control group but 25% of the experimental group had naïve views, which is difficult to explain. These figures indicate that the ERGI laboratory practical activities had a reasonable effect on male students' understanding of IC and a large effect on female students' understanding of IC.

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4.2.2.2.6 Social and cultural values (SC)

Poor understanding of this aspect was demonstrated by males and females in the control group. Only 13% of females and 7% of males expressed informed views in the control group. The number of female students with informed views was slightly more than that of the male students by a reasonable margin of 6%.

For males, 19% of the experimental group (ME) and 7% of the control group (MC) showed informed views of SC, a noticeable difference of 12 pp. Similarly, for females, 17% of the experimental group (FE) and 13% of the control group (FC) demonstrated informed views of this aspect, a small difference of 4 pp.

These results indicate that though the social and cultural aspects of NOS were poorly understood, the ERGI laboratory practical activities had a noticeable effect on male students' understanding of SC and a small effect on female students' understanding of SC.

4.2.2.2.7 Scientific method (SM)

Poor understanding of this aspect was shown by male and female students in the control group. In the control group, only 12% of the males and no females had an informed understanding of this aspect.

For males, 23% of the experimental group (ME) and 12% of the control group (MC) showed informed views of SM, a noticeable difference of 11 pp. Similarly, for females, 8% of the experimental group (FE) and 0% of the control group (FC) demonstrated informed views of this aspect, a reasonable difference of 8 pp. These figures indicate that the ERGI laboratory practical activities had a noticeable effect on males' as well as a reasonable effect on females' understanding of SM. SM understanding of males as well as females remained poor despite the improvement.

4.2.3 Relationship between the understanding of NOS and academic achievement in physics

The relationship between the understanding of NOS and academic achievement was investigated by dividing both the control and experimental groups into top half of class (high achieving students) and bottom half of class (low achieving students) based on their marks in the theoretical year-end examination. The data were first analysed by comparing the differences between the high and low achievers in the control group. Although there were differences in the various aspects of NOS, overall, there was no difference between the high and low achievers. Hereafter, the academic achievement in the control and experimental groups were investigated in order to determine if the ERGI laboratory practical activities had a different effect on high achievers than on low achievers. The results show that overall the low achievers showed a slightly stronger effect than the high achievers.

4.2.3.1 Difference in the understanding of NOS aspects between the academically high and low achieving students in the control group.

Table 4.4 and Figure 4.6 show the percentage of students expressing informed, mixed and naïve views per VNOS aspect after the completion of the practical course, for both the academically high achieving and the academically low achieving students in the control group. For easy comparison, Figure 4.7 shows only the percentage of students expressing

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Table 4.4 Percentage of the academically high achieving (HC) and the academically low achieving (LC) students expressing informed, mixed and naïve views per NOS aspect, in the control group.

NOS	Informed (%)		Mixed (%)		Naïve (%)	
aspect	HC	LC	HC	LC	HC	LC
TN	38	25	54	33	8	42
EN	67	71	25	7	8	21
TL	8	14	8	14	83	71
OI	33	57	17	0	50	43
IC	23	21	77	50	0	29
SC	17	0	8	15	75	85
SM	15	13	69	56	15	31
Overall	29	29	38	26	33	45

informed views per NOS aspect. Comparing the overall results for the academically high and low achieving students in the control group, it seems that there is no difference in the performance of the two groups, with 29% of students in both groups having an informed view. However, in the individual aspects, there are differences. The EN was, in both cases, by far the best understood NOS aspect. It was slightly better understood by the low achieving students (67% of HC vs.71% of LC, p = 1.000). A good understanding of OI was shown by the low achievers (57%), but surprisingly, this aspect was only reasonably well understood by the high achievers (33%) (p = 0.267). In contrast, the high achievers performed 13 pp better than the low achievers (38% in the HC and 25% in the LC respectively gave informed views, p = 0.67) in the TN. A reasonably good understanding of IC (23% HC vs. 21% LC, p = 1.000) was demonstrated by high as well as low achievers, while both groups showed a poor understanding of TL (8% HC vs. 14% LC, p = 1.000), SC (17% HC vs. 0% LC, p = 0.220) and SM (15% HC vs. 13% LC, p = 1.000).

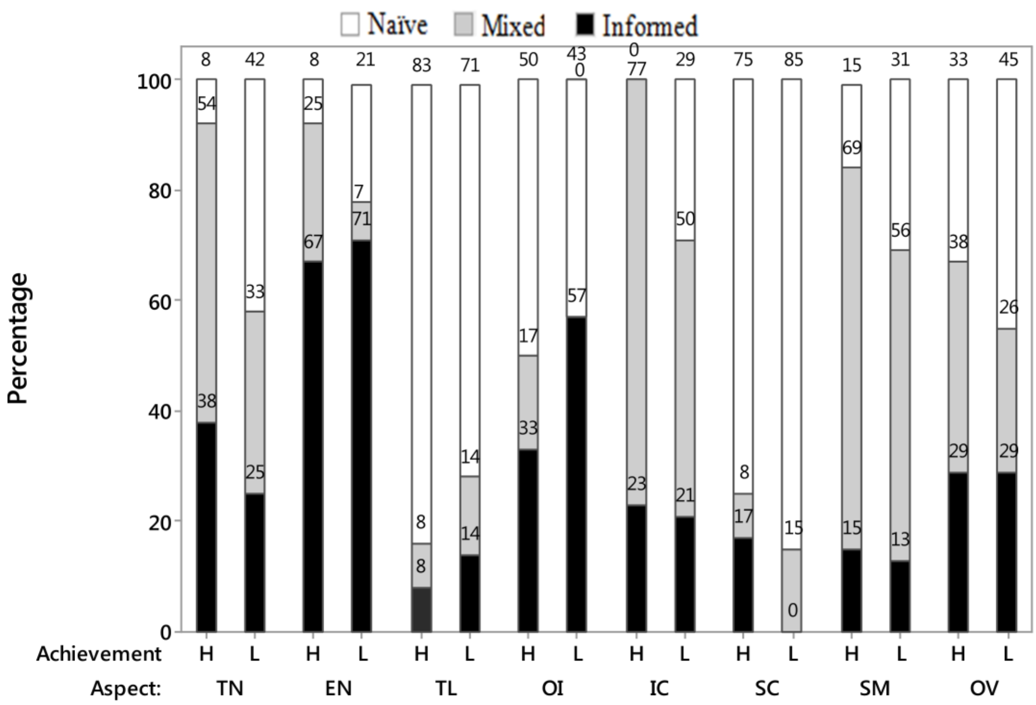

Figure 4.6 Percentage of the academically high achieving and the academically low achieving students expressing informed, mixed and naïve views per NOS aspect, in the control group.

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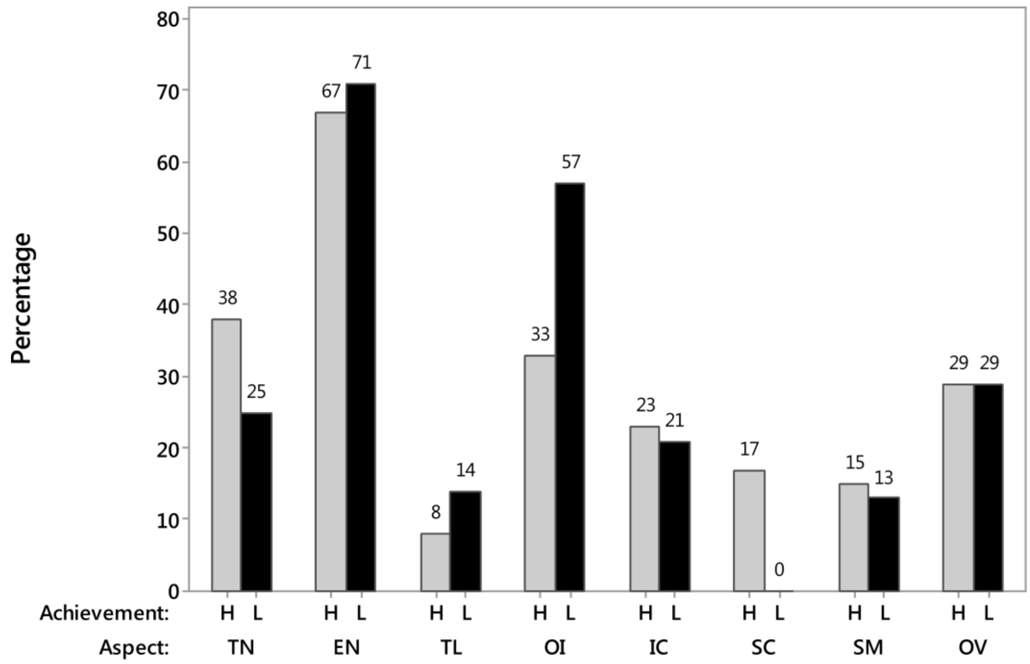

Figure 4.7 Percentage of academically high and low achieving students expressing informed views per NOS aspect, in the control group.

4.2.3.2 Relationship between ERGI laboratory practical activities and the understanding of NOS aspects by the academically high and low achieving students

Table 4.5 and Figure 4.8 show percentages of students expressing informed, mixed and naïve views per VNOS aspect, for the high and the low achieving students in both the control and experimental groups. EN was generally well understood, with only small differences amongst the HC, HE, LC, LE. In most NOS aspects, the differences between the control and experimental groups did not differ notably between the high and low achievers. The exceptions were OI and SC. For OI, the academically high achievers in the experimental (HE) group performed 5 pp better than the corresponding academically high achievers in the control group (HC). However, the low achievers in the control group (LC) performed 10 pp better than those in the experimental group (LE), suggesting that the ERGI laboratory practical activities had a negative effect on lower achievers for OI. In contrast, in SC, the high achievers in the experimental group performed only 3 pp better than those in the control group, while the low achievers in the experimental group performed 25 pp better than those in the control group. This indicates that the ERGI laboratory practical activities had a large effect on the low achievers for this NOS aspect.

On average, the academically low achievers in the experimental group performed 4 pp better than the academically high achievers (40% in the LE and 36% in the HE respectively gave informed views) in the VNOS test, suggesting that ERGI laboratory practical activities, on average, had a slightly stronger effect on low achieving students than on high achieving students.

4.2.3.2.1 Tentative nature (TN)

The high and low achievers in the control group demonstrated a reasonably good understanding of this aspect, with 38% of HC and 25% of LC showing informed views, as

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Table 4.5 Percentage of high achieving students and the low achieving students expressing informed, mixed and naïve views per NOS aspect, in the control and experimental groups.

	Informed (%)				Mixed (%)				Naïve (%)			
NOS aspect	**HC**	**HE**	**LC**	**LE**	**HC**	**HE**	**LC**	**LE**	**HC**	**HE**	**LC**	**LE**
TN	38	53	25	47	54	33	33	20	8	13	42	33
EN	67	69	71	75	25	23	7	25	8	8	21	0
TL	8	27	14	25	8	33	14	25	83	40	71	50
OI	33	38	57	47	17	38	0	24	50	25	43	29
IC	23	40	21	38	77	40	50	44	0	20	29	19
SC	17	20	0	25	8	7	15	19	75	73	85	56
SM	15	13	13	25	69	88	56	75	15	0	31	0
Overall	29	36	29	40	38	38	26	33	33	26	45	27

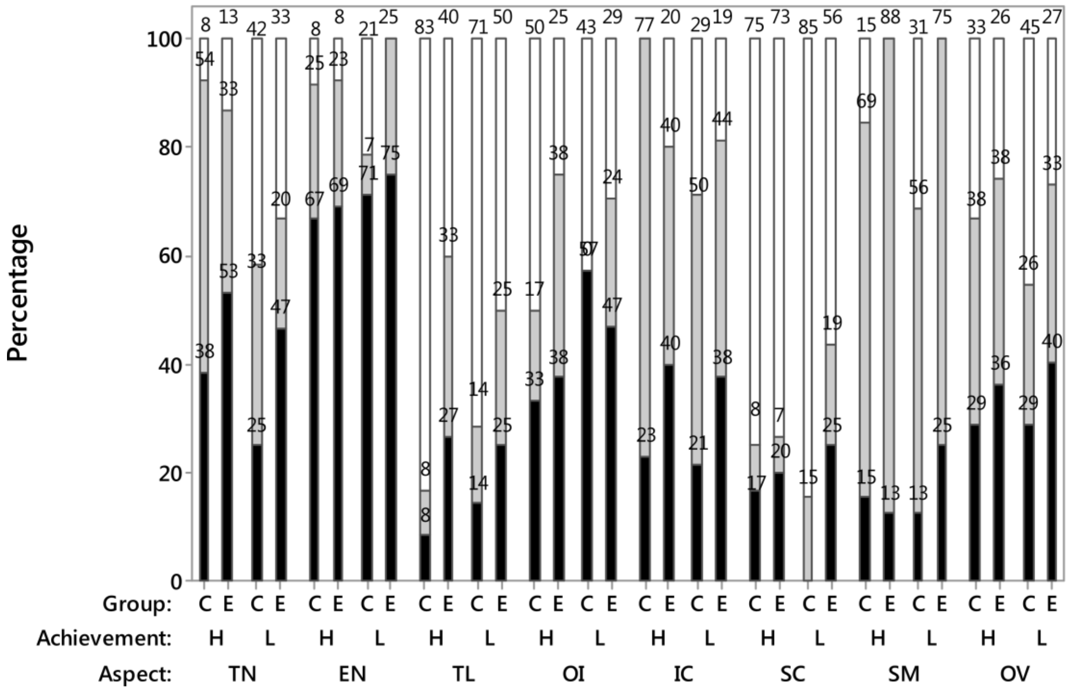

Figure 4.8 Percentage of the high (H) achieving and low (L) achieving students expressing informed, mixed and naïve views per NOS aspect, in the control (C) and experimental (E) groups.

seen in Table 4.4. However, the high achievers performed better by a noticeable margin of 13%.

From Table 4.5, 53% of HE and 38% of HC showed informed views of TN, amounting to a noticeable difference (15 pp) between the number of high achievers in the experimental group and the control group having informed views. The lower achievers in the sample showed a similar but larger difference, where 47% of LE and 25% of LC demonstrated informed views of TN, a large difference of 22 pp. These figures indicate that the ERGI laboratory practical activities had a large effect on the low achievers' understanding of TN and a noticeable effect on the high achievers' understanding of TN.

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4.2.3.2.2 Empirical nature (EN)

The high and low achievers in the control group demonstrated a good understanding of this aspect (67% of HC and 71% of LC respectively, demonstrated informed views). The low achievers in the control group demonstrated more informed views than high achievers by a small margin of 4%.

For the high achievers, 69% of the experimental group and 67% of the control group showed informed views of EN. There was a small difference (2 pp) in the number of students having an informed view between HE and HC. The low achievers showed a similar small trend with 75% of LE and 71% of LC demonstrating informed views of EN, a small difference (4 pp). These figures suggest that the ERGI laboratory practical activities had a small effect on both groups' understanding of EN.

4.2.3.2.3 Theory vs. law (TL)

The high and low achievers in the control group demonstrated a poor understanding of this aspect (8% of HC and 14% of LC respectively, demonstrated informed views). The low achievers in the control group demonstrated more informed views than high achievers by a reasonable margin of 6%.

From Table 4.5, 27% of HE and 8% of HC showed informed views of TL, amounting to a noticeable difference (19 pp) between the number of high achievers in the experimental group and the control group having informed views. The lower achievers in the sample showed a similar but smaller noticeable difference, where 25% of LE and 14% of LC demonstrated informed views of TL, a noticeable difference of 11 pp. These figures indicate that the ERGI laboratory practical activities had a noticeable effect on both the low achievers' and the high achievers' understanding of TL.

4.2.3.2.4 Observation vs. inference (OI)

The high and low achievers in the control group demonstrated a reasonable understanding of this aspect (33% of HC and 57% of LC respectively, demonstrated informed views). The low achievers in the control group demonstrated more informed views by a large margin of 24%.

For the high achievers, 38% of the experimental group and 33% of the control group showed informed views of OI. There was a small difference (5 pp) in the number of students having an informed view between HE and HC. The low achievers showed a negative effect with 47% of LE and 57% of LC demonstrating informed views of OI, a noticeable difference (10 pp). These figures indicate that the ERGI laboratory practical activities had a noticeable negative effect on the low achievers' understanding of OI and a small effect on the high achievers' understanding of OI.

4.2.3.2.5 Imagination and creativity (IC)

The high and low achievers in the control group demonstrated a reasonable understanding of this aspect (23% of HC and 21% of LC respectively, demonstrated informed views). The high achievers in the control group demonstrated more informed views than low achievers by a small margin of 2%.

For the high achievers, 40% of the experimental group and 23% of the control group showed informed views of IC. There was a noticeable difference (17 pp) in the number of students

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having an informed view between HE and HC. On the other hand, there was an anomaly in the naïve views where there is a large difference of 20 pp (20% in the HE and 0% in the HC) which is difficult to explain.

The low achievers showed a similar trend with 38% of LE and 21% of LC demonstrating informed views of IC, a noticeable difference (17 pp). These figures suggest that the ERGI laboratory practical activities had a noticeable effect on both the low achievers' and the high achievers' understanding of IC.

4.2.3.2.6 Social and cultural values (SC)

The high as well as the low achievers in the control group demonstrated a poor understanding of this aspect (17% of HC and 0% of LC, respectively, demonstrated informed views). The high achievers in the control group demonstrated more informed views than low achievers by a noticeable margin of 17%.

For the high achievers, 20% of the experimental group and 17% of the control group showed informed views, amounting to a small difference (3 pp) between the number of high achievers in the experimental group and the control group having informed views. For naïve views, there was a small difference of 2 pp in the number of naïve views (73% in the HE and 75% in the HC). The low achiever showed a similar but stronger trend, with 25% of LE and 0% of LC demonstrating informed views of SC, a large difference of 25 pp. These figures indicate that the ERGI laboratory practical activities had a large effect on the low achievers' understanding of SC and a small effect on the high achievers' understanding of SC.

4.2.3.2.7 Scientific method (SM)

The high and low achievers in the control group demonstrated a poor understanding of this aspect (15% of HC and 13% of LC respectively, demonstrated informed views). The high achievers in the control group demonstrated more informed views by a small margin of 2%.

From Table 4.5, 13% of HE and 15% of HC showed informed views of SM, amounting to a very small difference (2 pp) between the number of high achievers in the experimental group and the control group having informed views. This difference indicates a very small negative effect, not just as difference in understanding SM.

The lower achievers in the sample showed a positive effect, where 25% of LE and 13% of LC demonstrated informed views of SM, a noticeable difference of 12 pp. These figures indicate that the ERGI laboratory practical activities had a noticeable effect on the low achievers' understanding of SM and a small negative effect on the high achievers' understanding of SM.

4.3 Students' views on the practical course: Focus group interviews

In this section an analysis of the students' views on the practical course are presented. Responses of students in both groups to various questions posed in the form of FGI were analysed. In the numbering system used, a code e.g. V15 is used to identify participants who took part in the FGI in the current study. The analysis of students' attitudes is discussed and illustrated by informative examples of students' responses.

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4.3.1 Analysis of responses given in focus group interviews

When asked how they experienced the practical activities, some representative responses are given below:

> *V3 (experimental group) (FGI q.1): "The experience was good. It helped me to understand more the questions in the test. I also learnt how different formulas should be used and how they are applied in everyday life."*

> *V23 (experimental group) (FGI q.1): "Okay, basically the practical activities were fine not difficult but they actually exposed us to variety of physics things that we did not know about before. Like, the apparatus we were using during the practicals and some other physics concepts that we actually learnt in class. But we didn't know how to apply, we were actually given chance to actually see the application of those physics concepts during the practicals. Like for example, connecting those circuits. We only knew how to draw the circuit but didn't actually know how to connect what materials until we do the physics practicals."*

These quotations illustrate that the students who did the ERGI laboratory practical activities felt that the practical activities aided their understanding and gave them more confidence in applying physics. The students did not find the practical activities difficult and felt they were exposed to new knowledge and apparatus.

Students in the control group expressed their views by saying

> *V15 (control group) (FGI q.1): "The important thing we have done as you start the practicals you get your information sheet. And then it will describe how you will set up the equipment and that was very important part. Because you give that much preparation about terminology, about the practical you are going to do beforehand. But unless all those instructions for setting up the equipment were clear, all the preparation will mean nothing."*

> *V61 (control group) (FGI q.1): "They were fine for me because we got instructions and we knew basically the outline of practicals. So we knew what to do sort of most of them but then as she said if you don't know the work behind the practicals then you became bit sketchy. There was also a chance to realise how much you know of your work at the time that u can study further for upcoming examinations."*

These comments by students in the control group found the instructions and descriptions in the practical sessions important. Although they also mentioned the importance of preparation and background knowledge, it is clear from these two answers that the students felt a need for clear recipes.

All the students (control and experimental) did ERGI laboratory practical activities in the first semester. This provided an interesting opportunity for students to compare their experience in the practical sessions:

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V15 (experimental group) (same student as above) (FGI q.1): "I also felt the practicals were more interactive, like they gave us more chance to work with senses and variety of skills than the last semester once."

V44 (control group) (FGI q.1): Generally, "I would say (second semester practical session) is better than the first semester practicals. There was bit more independence, I felt and there wasn't much guidance in the practicals itself, which gave one more chance to think, initially you have to figure out what to do."

In comparing their experiences, the student from the experimental group clearly realised the benefit of ERGI laboratory practical activities, and seems to have gained confidence in problem solving. However, the student in the control group expressed his need for clear guidance, although he realised that the lack of recipe-like instructions did force him to think about what he was doing, which suggests that the student is still reliant on recipes.

Students in both control and experimental groups felt that, after the practical course, the practical laboratory activities did encourage them to interrogate their views. They also felt that it encouraged team work amongst students and that through group discussions problems could be easily resolved.

Both groups expressed the view that their thinking abilities and their understanding of different scientific theories were enhanced while engaged in the practical course. During interviews students were asked some questions pertaining to their views on science as a discipline after participating in the practical course. Students expressed enthusiasm and appreciation, e.g.:

V8 (experimental group) (FGI q.5): "I think science especially physics and like chemistry is a study of the physical universe, especially the ways in which mathematics describes the universe. And it differs from subjects like political science because it is describing physical universe rather than social interactions. Yes, well I think the practicals did demonstrate what we were learning about in theory or what we know in theory. So that when we see things in the real world, we understand how it all fits together, what is actually going on behind the bigger main concept."

V13 (control group) (FGI q.5): "The reason why I like Physics so much is because of how in-depth it goes into everything that we take for granted. Just everything like down to atomic scale, how everything works together so perfectly and how the random chance of us being as we are. Everything working together is so slim that it is practically impossible for it to happen, yet it has. And how it investigates everything to such a degree that afterwards it is so mind blowing what you have learnt and what you have discovered. We are here, every day we learn more and science is just learning on just too high degree to everything else. That is why I love doing science. Well in the end it is just a way of investigation into everything that you are learning you are proving whatever theories, you have just said. And I do not think that there is change of more that executed me to do more practicals to enhance interactiveness of the theory that you have learnt."

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In addition, guiding questions did not only enhance students' thinking skills, but they also empowered them to understand the link between real world events and class knowledge. During the FGI, students indicated that:

> *V23 (experimental group same student as above) (FGI q.1): "Okay, basically the practical activities were fine not difficult but they actually exposed us to variety of physics things that we did not know about before. Like, the apparatus we were using during the practicals and some other physics concepts that we actually learnt in class. But we didn't know how to apply, we were actually given chance to actually see the application of those physics concepts during the practicals, for example, connecting those circuits. We only knew how to draw the circuit but didn't actually know how to connect what materials until we do the physics practicals."*

> *V49 (control group) (FGI q.1): "I think that, the thing is, it really made it easier to relate to the theory and the fact that practical did not take that much preparation. I think that was nice because the thing is like we do not have time to spend hours and hours to prepare for something. And then the fact that usually we were preparing for an hour may be for the practicals and it was not that hard. You can actually like see how everything is coming together. You can see the full picture when doing the practicals, because they made it easier to understand the topic and they made it easier to write test because like if you forgot something, you can think ohh what did we do in a practical and you could actually make a comeback from that."*

The use of the practical course integrated with NOS explicit reflective guiding questions assisted students in both groups to demonstrate a reasonable change in attitude towards science content and science learning. The use of guiding questions might have encouraged individual independence and might have assisted students in the discovery of science knowledge.

Comparing the experiences of the first and second semester during interviews, the experimental group as well as the control group students expressed the view that GI was better than recipe-based because it enabled them to retain learnt knowledge in their long term memories. Students expressed these views after being asked whether they would prefer more guidance in the practical activity or more opportunity to investigate on their own.

Students comments received included:

> *V15 (control group same student as above) (FGI q.2): "I think the one where you investigate on your own (they all seem to agree). If you are given guidelines then it will be more of doing theory work whereas you are just confirming it. Whereas when you are investigating on your own you could discover things for your own and is usually your own discoveries are remembered more because they are more important to you, because you discovered them on your own instead of doing someone' s work."*

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V23 (experimental group same student as above) (FGI q.2): "I would prefer to investigate on my own, so that I figure out things on my own. Because when you are guided you just follow the procedure but then at the end of the day you acquire less knowledge than when you do things on your own and see what is going on, like individually."

V39 (experimental group) (FGI q.2): "It is also nice (the one where you are given more opportunity to investigate on your own) because it actually make you think of what you are doing and giving the thing of like challenging yourself, like okay maybe if I do this and then maybe it will work. If I do this let us just see what happens on my own. And if you felt like then you just can't, you can ask the demonstrator to come and help."

V49 (control group same student as above) (FGI q.2):" I agree with that because there is a thing like if you actually have to struggle to get something right you are going to remember like what you got wrong and what you got right on your own. Whereas if you get guidelines you are going to forget because it is just like a routine, just listen and repeat. You won't like make some conclusions on your own it will be somebody's work on your paper. I think that is repeating the same thing over and over again."

Although students in the control group demonstrated a change in attitudes compared to the students in the experimental group, students in both groups still believed after the course that physics as a discipline was concerned mainly with calculations and was not linked with what is happening in real life. These results show that the ERGI laboratory practical activities had little effect in shifting students' attitudes about the learning of physics.

However, during interviews many participants did indicate that ERGI laboratory practical activities were very helpful compared to recipe based practical activities in understanding theoretical content in class. The current study was conducted during the second semester after students have completed their first semester recipe-based physics practical activities. Experimental group students expressed their views by saying:

V8 (experimental group same as above) (FGI q.1): "I enjoyed the practical sessions this semester (second semester).They were much easier than last semester's practicals (first semester's practicals). Although the format wasn't very much different, the practicals were just easier. And also when we covered the work in the lectures, we had already done some of the practicals that were related to the classroom's theory content."

V59 (experimental group) (FGI q.1): "At first, I did not see point to go but as time progressed I actually saw that they helped because like the practicals that I did not understand. I also did not understand the work that we did in classroom so those practicals did help."

It is clear that the students experienced growth in that they realised the value of the ERGI laboratory practical activities. These views were common amongst the students after the

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course. They indicated that the practical course did lay a good foundation for the lectures that they received after the practical sessions.

The above views were again echoed in FGI q.5 in which students were asked whether the practical course changed the way they viewed science. Many students indicated that practical activities enabled them to understand how abstract physics concepts could be translated into concrete actions that could be seen and how different natural phenomena work. This was the case for both the experimental and the control group:

> *V8 (experimental group same as above) (FGI q.5): "Yes, well I think the practicals did demonstrate what we were learning about in theory or what we know in theory. So that when we see things in the real world, we understand how it all fits together, what is actually going on behind the bigger main concept."*

> *V49 (control group same student as above) (FGI q.5): "I do not think like my view changed about science but I think it really got enhanced. And I felt more certain about what I felt about science, because the thing is like now being able to prove staff and being able to see the law in front of you, like you see it actually hands on. You actually experience like that is happening, that is the truth and that makes you comfortable with science. And interacting with it, because I think some people might escape, because it so much info that you do not know where to like take a word or what to leave because you are so scared that there is so much laws such that you need to memorise. But now after like doing all the practicals, I think it really enhanced the fact that I now believe in laws when I see them on paper. So when something is now given I will actually believe more than I used to."*

4.4 Academic performance

In this section, the academic performance by the control and experimental group students is discussed. In the first Section (4.4.1) the performance of the control and experimental groups in the combined practical and theoretical year-end examinations is compared. The combined practical examination is further subdivided into two sections namely a written practical examination and a hands-on practical examination, which are discussed in Sections 4.4.1.1 and 4.4.1.2 respectively. In Section 4.4.1.3 the relationship between ERGI laboratory practical activities and the aggregate grades (combined practical examination mark, theoretical year-end examination and aggregate grade) is discussed. The overall practical mark comprised of an equal weighting of the average mark obtained for all experiments and the combined practical examination mark. The practical mark comprised 20% of the semester mark and the aggregate grade was comprised of equal weighting of the semester and theoretical year-end examination mark.

The results indicate only small differences between the academic performance of the two groups in both the theoretical year-end examination and the combined practical examination, as well as in the aggregate grades. However, when individual questions in the written practical examination were compared, significant differences in performance between the two groups were, observed.

In the second Section, (4.5.2), the above results are analysed further by subdividing the groups into high and low achieving students. As expected, the high achieving students

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generally scored better than the low achieving students. However, when the effect of ERGI practical activities on their performance in individual questions was analysed, it became clear that for some questions the ERGI laboratory practical activities seemed to have had a positive effect on the performance of both groups, while for other questions there was a positive effect on the performance of the high achieving students and a negative effect on the performance of the low achieving students. This effect could be attributed to the level of difficulty of the ERGI laboratory practical activities associated with the question, where the low achieving students could not follow the argument and therefore failed to benefit from the ERGI laboratory practical activities.

4.4.1 The relationship between ERGI laboratory practical activities and students' performance in the combined practical and theoretical year-end examinations.

In this section the performance of the control and experimental student groups in the practical and theoretical year-end examination is discussed. The combined practical examination was composed of two parts, namely written practical examination and hands on-practical examination, with the practical examination mark equal to the sum of the marks obtained in the two sections. The scores for the 2 groups on these sections are summarised in Table 4.6. In the written practical examination (discussed in Section 4.4.1.1), the control group did slightly better (4 pp) than the experimental group. In the hands-on section (discussed in Section 4.4.1.2), both groups obtained the same mark of 74%.

Hereafter, the performance of the control and experimental groups in the individual questions in the combined practical examination is discussed. Effect of ERGI laboratory practical activities on the combined practical examination for the control and experimental groups is discussed in Section 4.4.1.3. In Section 4.4.1.4, Relationship between ERGI laboratory practical activities and the aggregate grades for the control and experimental groups is discussed.

4.4.1.1 Written practical examination

The marks obtained in individual questions of the written practical examination by the control and experimental student groups, respectively, are shown in Table 4.6 and are presented graphically in Figure 4.9. From this table, it may be seen that overall the control group did better in the written practical examination. In the next section, more light is shed on this phenomenon when the performance of the academically low and high achieving students is analysed separately.

The performance of the students in the individual questions is discussed below.

Question 1: Proper connection of V and A meters (V&A meters)
This question was poorly answered by students in both the control and experimental groups. The experimental group performed 5 pp better than the control group after completion of the practical course (C obtained a score of 23% and E 28%). These results suggest that that the ERGI laboratory practical activities had a small effect on the experimental group students' understanding of the connection of voltmeters and ammeters.

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Table 4.6 Average scores of the experimental and control groups in individual questions of the combined practical examination. Full text of the combined practical examination is included in Appendix J and K.

	Short summary of question	Marks	Average score (%) C	E	E-C (pp)
	Combined practical examination	–	64	62	–2
	Written section of practical examination	–	60	56	–4
	Hands-on section of practical examination	–	74	74	0
1	Proper connection of V and A meters (V&A meters)	[4]	23	28	5
2a	Explaining exponential decay and theoretical calculations (Exponential decay)	[4]	41	42	1
2b	Definition of half-life (Half-life)	[2]	47	62	**15**
3a	Experimental details of SHM: Relationship between the measured force and position of the mass. (SHM)	[4]	51	48	–3
3b	Explaining two different methods of determining spring constant of a spring. (Spring const.)	[4]	41	44	3
4	Explain working of current balance (Current balance)	[10]	40	35	–5
5	Drawing a transformer circuit diagram with voltmeters and ammeters (Transformer V and A)	[8]	72	74	2
6	Determine amplitude and frequency of a signal displayed on an oscilloscope. (Oscilloscope)	[5]	61	60	–1
7a	Explain what the function of the Trigger of an oscilloscope. (Trigger 1)	[3]	28	26	–2
7b	What do trigger level and trigger slope refer to? (Trigger 2)	[2]	28	13	–15
8a	Linearize a graph of capacitive reactance vs. frequency (Linearization of graph).	[3]	49	57	8
8b	Plotting of a graph (Plotting graph)	[10]	72	69	–3
8c	Calculate C from graph (Calculate C from graph)	[4]	35	28	–7
A.	The oscilloscope hands-on practical examination	[10]	81	78	–3
B.	The multimeters hands-on practical examination	[10]	48	52	4
C.	The transformer hands-on practical examination	[10]	95	93	–2

Question 2a: Explaining exponential decay and theoretical calculations (Exponential decay)

Students in both the control and experimental groups showed an average performance in this question. The experimental group performed 1 pp better than the control group on this question after completion of the practical course (C obtained a score of 41% and E obtained a score of 42%). These results suggest that the ERGI laboratory practical activities had a very small effect on the experimental group's understanding of exponential decay and theoretical calculations.

Question 2b: Definition of half-life (Half-life)

Students in both the control and experimental groups showed an average performance in this question. The experimental group performed 15 pp better than the control group after completion of the practical course (C obtained a score of 47% and E 62%). These results suggest that the ERGI laboratory practical activities had a noticeable effect on experimental group's understanding of half-life.

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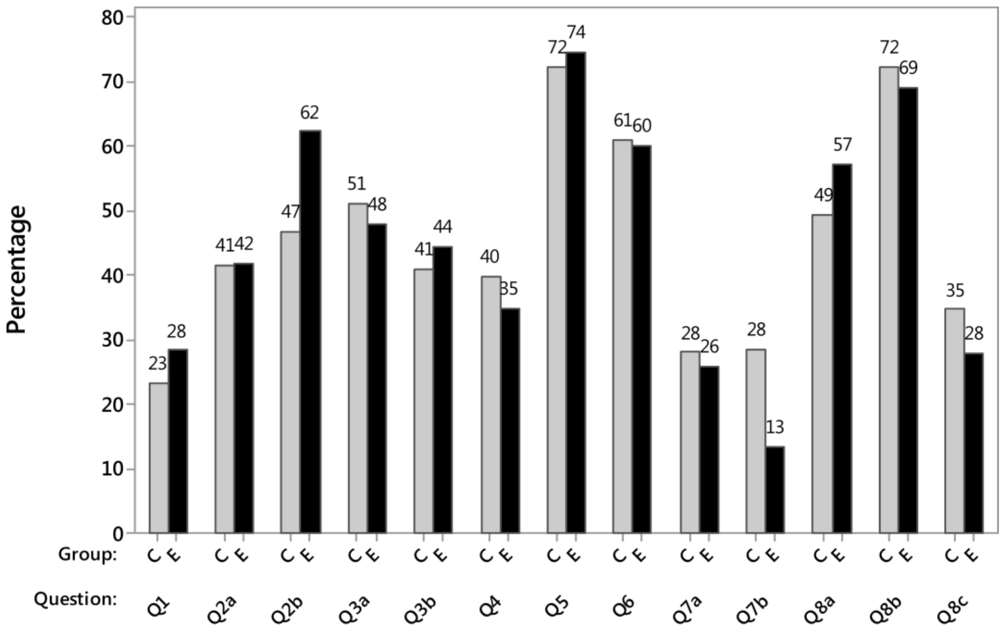

Figure 4.9 Average scores obtained by students in the individual questions of the written practical examination for the control and experimental groups.

Question 3a: Experimental details of SHM: Relationship between the measured force and position of the mass (SHM)
Students in both the control and experimental groups showed an average performance in this question. The control group performed 3 pp better than the experimental group after completion of the practical course (C obtained a score of 51% and E 48%). These results suggest that that the ERGI laboratory practical activities had a reasonably large negative effect on the experimental group's understanding of the relationship between the measured force and position of the mass in the SHM experiment. The large difference in the performance of the two groups is investigated further in the next section, where the academically low and high achieving students are compared.

Question 3b: Explain two different methods of determining the spring constant of a spring (Spring const.)
Students in both the control and experimental groups showed an average performance in this question. The experimental group performed 3 pp better than the control group after completion of the practical course (C obtained a score of 41% and E 44%). These results suggest that that the ERGI laboratory practical activities had a small effect on the experimental group's ability to explain the two different methods of determining the spring constant of a spring.

Question 4: Explain the working of the current balance **(Current balance)**
This question was poorly answered by students in the experimental group, while those in the control group showed an average performance. The control group performed 5 pp better than the experimental group after completion of the practical course (C obtained a score of 40% and E 35%). These results suggest that the ERGI laboratory practical activities had a small negative effect on the experimental group's understanding of the working of the current balance.

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Question 5: Draw a transformer circuit diagram with voltmeters and ammeters (Transformer V and A)

This question was answered well by students in both the control and experimental groups. The experimental group performed 2 pp better than the control group after the completion of the practical course (C obtained a score of 72% and E 74%). These results suggest that the ERGI laboratory practical activities had a small effect on the experimental group's ability to draw the circuit diagram of a transformer with voltmeters and ammeters.

Question 6: Determine the amplitude and frequency of a signal displayed on an oscilloscope (Oscilloscope)

Students in both the control and experimental groups showed an average performance in this question.The control group performed 1 pp better than the experimental group after completion of the practical course (C obtained a score of 61% and E 60%). These results suggest that that the ERGI laboratory practical activities had a very small negative effect on the experimental group's ability to determine amplitude and frequency of a signal from an oscilloscope display.

Question 7a: Explain the function of the trigger of an oscilloscope (Trigger 1)

This question was answered poorly by students both in the control and experimental groups. The control group performed 2 pp better than the experimental group after completion of the practical course (C obtained a score of 28% and E 26%). These results suggest that the ERGI laboratory practical activities had a very small negative effect on the experimental group's understanding of what the function of the trigger on an oscilloscope is.

Question 7b: Explain what do trigger level and trigger slope refer to? (Trigger 2)

This question was answered poorly by students in both the control and experimental groups. The control group performed 15 pp better than the experimental group after completion of the practical course (C obtained a score of 28% and E 13%). In this question, the control group performed markedly better than the experimental group. The matter is examined in more detail in the next section, where the performance of high and low achieving students is compared. These results suggest that the ERGI laboratory practical activities had a noticeable negative effect on the experimental group's understanding of what the trigger level and trigger slope refer to.

Question 8a: Linearize a graph of capacitive reactance vs. frequency (Linearization of graph)

Students in both the control and experimental groups showed an average performance in this question. The experimental group performed 8 pp better than the control group after completion of the practical course (C obtained a score of 49% and E 57%). These results suggest that the ERGI laboratory practical activities had a reasonable effect on the experimental group's understanding of linearizing graphs.

Question 8b: Plotting of a graph (Plotting graph)

Students in both the control and experimental groups showed an average performance in this question. The control group performed 3 pp better than the experimental group after completion of the practical course (C obtained a score of 72% and E 69%). These results suggest that the ERGI laboratory practical activities had a small negative effect on the experimental group's ability to plot a graph.

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Question 8c: Calculate C from graph (Calculate C from graph)
This question was answered poorly by students in both the control and experimental groups. The control group performed 7 pp better than the experimental group after completion of the practical course (C obtained a score of 35% and E 28%). These results suggest that the ERGI laboratory practical activities had a reasonably large negative effect on the experimental group's understanding of calculating quantities from a graph.

4.4.1.2 Hands-on practical examination

First the reader is reminded that all students did all examinations. The marks obtained in hands-on practical examination by control and experimental group students are shown in Table 4.6 and are presented graphically in Figure 4.10. There were three experiments in the hands-on practical examination.

The oscilloscope hands-on practical examination
The students in the control and experimental groups performed well in this hands-on practical examination. The control group performed slightly better (3 pp) compared to the experimental group, (C obtained 81% and E 78%). This shows that the ERGI laboratory practical activities had a small negative effect on the experimental group's performance on this hands-on practical examination.

The multimeters hands-on practical examination
The students in the control group demonstrated a reasonable performance and those in the experimental group showed a good performance in this hands-on practical examination. The experimental group performed slightly better (4 pp) than the control group, (C obtained 48% and E 52%). This shows that the ERGI laboratory practical activities had a small effect on the experimental group's performance on this hands-on practical examination.

The transformer hands-on practical examination
The students in the control and experimental groups showed the best performance in this hands-on practical examination. The control group performed slightly better (2 pp) than the experimental group, (C obtained 95% and E 93%). This shows that the ERGI laboratory practical activities had a small negative effect on the experimental group's performance in this hands-on practical examination.

4.4.1.3 Effect of ERGI laboratory practical activities on the combined practical examination

Table 4.7 covers the combined practical examination, i.e. written and hands-on practical examinations.

Different concepts were addressed in the practical course and tested in the combined practical examination by means of short questions, the results of which are, in sequence of average effect, shown in Table 4.7. The ability of the ERGI laboratory practical activities to enhance students' knowledge of a concept was categorised in classes of "successful", "neutral" and "unsuccessful". Concepts were deemed to be successfully taught by ERGI laboratory practical activities when students in the experimental group performed better in answering an associated quest than those in the control group, for example in questions 2b (with a noticeable difference of 15 pp) and 8 (with a reasonably large difference of 8 pp).Questions

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in which the control group students outperformed the experimental group students indicated that the ERGI laboratory practical activities were "unsuccessful" in teaching the related concept, for example, questions 8c and 7b. ERGI laboratory practical activities were deemed to be "neutral" in enhancing learning if the experimental group students showed a small effect or no effect, for example the concepts addressed by questions 1, 3b, 5, 2a, 3a, 6, 7a, 8b and 4 respectively, as well as a hands-on practical examination such as the multimeter, the oscilloscope and the transformer.

These results show that the ERGI laboratory practical activities assisted the experimental group students in two of the individual questions (i.e. 2b and 8a) in the written practical examination. In the content addressed by questions 1, 3b, 5, 2a, 3a, 6, 7a, 8b and 4 respectively the ERGI laboratory practical activities showed a small effect on experimental group students' understanding of the physics content. In the content addressed by questions 8c and 7b the ERGI laboratory practical activities showed a negative effect on students' understanding of the physics content and they did not assist students in understanding the physics knowledge addressed by these questions.

4.4.1.4 Relationship between ERGI laboratory practical activities and the aggregate grades

The marks obtained by the students for the combined practical examination mark and theoretical year-end examination for the control and experimental groups are shown in Table 4.8. In the combined practical examination mark, the experimental group performed worse than the control group by a small margin of 2 pp. However, the experimental group performed 3 pp better than the control group in the theoretical year-end examination mark.

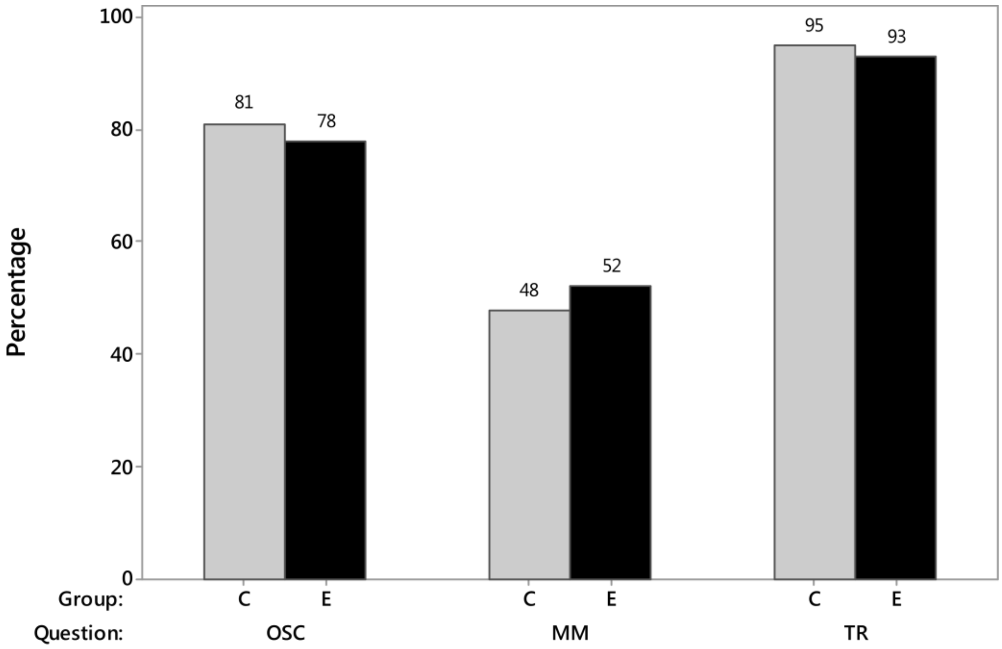

Figure 4.10 Average scores obtained by students in the hands-on practical examination question for the control and experimental groups.

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Table 4.7 Effect of ERGI laboratory practical activities on the combined practical examination**.**

Questions	Short summary	Effect (E-C) (pp)
Successful (Experimental group students performed better than the control group students)		
2b	Definition of half-life	15
8a	Linearize a graph of capacitive reactance vs. frequency	8
Neutral (Experimental group students and control group students performed similarly)		
1	Proper connection of V and A meters	5
C	Multimeter hands-on practical examination	4
3b	Explaining two different methods of determining spring constant of a spring	3
5	Draw a transformer circuit diagram with voltmeters and ammeters	2
2a	Explaining exponential decay and theoretical calculations	0
6	Determine amplitude and frequency of a signal displayed on an oscilloscope	–1
B	Transformer hands-on practical examination	–2
7a	Explain the function of the trigger of an oscilloscope	–2
3a	Experimental details of SHM: Relationship between the measured force and position of the mass	–3
A	Oscilloscope hands-on practical examination	–3
8b	Plotting of a graph	–3
4	Explain the working of the current balance	–5
Unsuccessful (Control group students performed better than the experimental group students)		
8c	Calculate C from graph	–7
7b	What do the trigger level and trigger slope refer to?	–15

Table 4.8 Average scores of the experimental and control groups in the combined practical examination mark and theoretical year-end examination mark.

	Average score (%)	
Short summary of question	**C**	**E**
Combined practical examination mark	64	62
Theoretical year-end examination mark	56	59

4.4.2 Relationship between ERGI laboratory practical activities and performance of academically high and low achieving students in the combined practical and the theoretical year-end examination.

In this section the performance of academically high and low achieving students in the control and experimental student groups in the practical and theoretical year-end examination is discussed. The combined practical examination was composed of two parts, namely written practical examination and hands-on practical examination, with the combined practical examination mark equal to the sum of the marks obtained in the two sections. Table 4.9 summarises the scores obtained in the combined practical examination. In the written

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Table 4.9 Average scores obtained by academically high and low achieving students in the experimental and control groups in the individual questions of the combined practical examination.

	Short summary of question	Marks	Average score (%) HC	HE	HE-HC	LC	LE	LE-LC
	Combined practical examination	–	67	68	**1**	64	64	**0**
	Written section of practical examination	–	61	63	**2**	60	59	**–1**
	Hands-on section of practical examination	–	80	76	**–4**	73	75	**2**
1	Proper connection of V and A meters (V&A meters)	[4]	21	31	**10**	25	37	**12**
2a	Explaining exponential decay and theoretical calculations (Exponential decay)	[4]	45	41	**–4**	44	43	**–1**
2b	Definition of half-life (Half-life)	[2]	46	71	**25**	44	62	**18**
3a	Experimental details of SHM: Relationship between the measured force and position of the mass. (SHM)	[2]	46	47	**1**	56	47	**–9**
3b	Explaining two different methods of determining spring constant of a spring. (Spring const.)	[4]	52	46	**–6**	36	43	**7**
4	Explain working of current balance (Current balance)	[10]	39	38	**–1**	37	38	**1**
5	Drawing a transformer circuit diagram with voltmeters and ammeters (Transformer V and A)	[8]	80	85	**5**	63	77	**14**
6	Determine amplitude and frequency of a signal displayed on an oscilloscope. (Oscilloscope)	[5]	66	74	**8**	55	57	**2**
7a	Explain what the function of the Trigger of an oscilloscope. (Trigger 1)	[3]	33	37	**4**	25	18	**–7**
7b	What do trigger level and trigger slope refer to? (Trigger 2)	[2]	29	29	**0**	31	6	**–25**
8a	Linearize a graph of capacitive reactance vs. frequency (Linearization of graph).d	[3]	67	57	**–10**	35	57	**22**
8b	Plotting of a graph (Plotting graph)	[10]	74	75	**1**	69	78	**9**
8c	Calculate C from graph (Calculate C from graph)	[4]	34	44	**10**	38	25	**–13**
	A. The oscilloscope hands-on practical examination	[10]	86	82	**–4**	78	76	**–2**
	B. The multimeters hands-on practical examination	[10]	55	53	**–2**	47	58	**11**
	C. The transformer hands-on practical examination	[10]	99	94	**–5**	95	89	**–6**

practical examination (discussed in Section 4.4.2.1), the HE performed slightly better (2 pp) than the HC, while the LC performed slightly better (1 pp) than the LE. In the hands-on practical examination (discussed in Section 4.4.2.2), the HC performed slightly better (4 pp) than the HE while the LE performed slightly better (2 pp) than the LC. Overall the HE performed slightly better (1 pp) than the HC, while the LE did not show an effect. Effect of ERGI laboratory practical activities on the combined practical examination for the

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academically high and low achieving students is discussed in Section 4.4.2.3. In Section 4.4.2.4, Relationship between ERGI laboratory practical activities and the aggregate grades for the academically high and low achieving students is discussed.

Note: There is a difference in the constitution of the groups for the combined practical examination mark, and theoretical year-end examination mark for the control and experimental group (Table 4.6 and 4.8) as well as the further analysis between sub-categories of high and low achieving students (Table 4.9 and 4.11). In the control and experimental groups all students' marks were included during the final analysis, whereas in the high and low achieving students only the marks of the students who wrote the theoretical year-end examination were used. Some students did not write the theoretical year-end examination, due to illness or dropping out, hence the difference that occurs in the average scores obtained by students. For instance, the average of HC and LC in Table 4.9 and 4.11 does not allways equal to the average of the control group in Table 4.6 and 4.8.

4.4.2.1 Written practical examination.

The marks obtained in individual questions of the written practical examination by the academically high and low achieving students are shown in Table 4.9 and are presented graphically in Figure 4.11.

Comparing the results for the academically high and low achieving students in the control and experimental groups (see Figure 4.11), although both groups followed the same trend, there were small differences between the scores obtained by the two groups for all the questions.

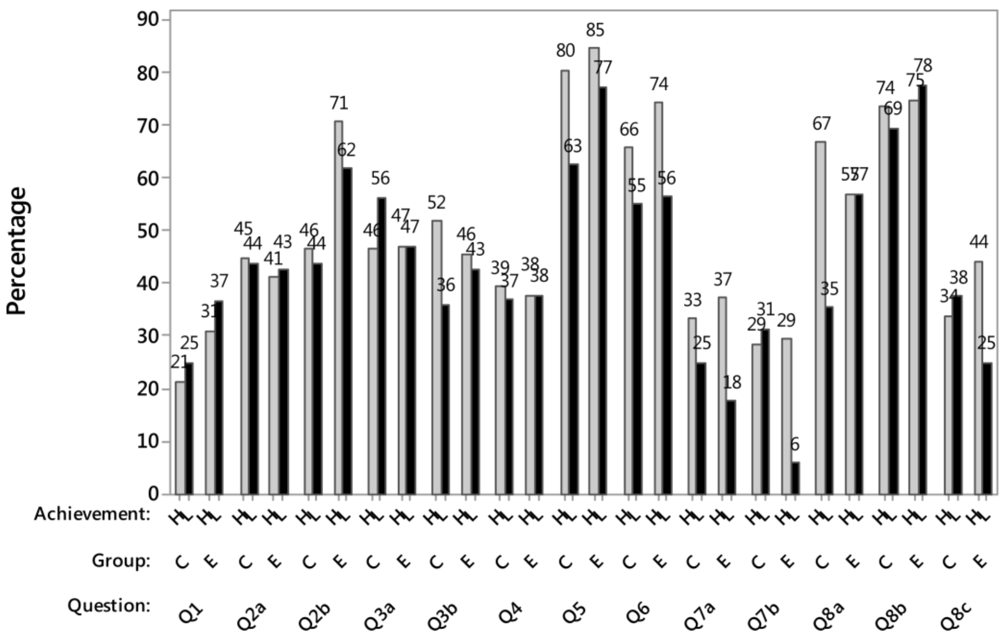

Figure 4.11 Average scores obtained by the academically high and low achieving students per individual written practical examination questions, in the control and experimental groups

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Question 1: Proper connection of V and A meters (V&A meters)
The high achievers in the experimental group (HE) performed 10 pp better than the high achievers in the control group (HC) in this question (HC obtained 21% and HE 31%). Similarly, the low achievers in the experimental group (LE) performed 12 pp better than the low achievers in the control group (LC) in this question (LC obtained 25% and LE 37%). These figures suggest that the ERGI laboratory practical activities had a noticeable effect on both HE's and LE's understanding of the connection of voltmeters and ammeters, with the effect slightly larger on the LE.

Question 2a: Explaining exponential decay and theoretical calculations (Exponential decay)
The HC performed 4 pp better than the HE in this question (HC obtained 45% and HE 41%). Similarly, the LC performed 1 pp better than the LE in this question (LC obtained 44% and LE 43%). These figures indicate that the ERGI laboratory practical activities had a small negative effect on HE's and a very small negative effect on LE's ability of explaining decay and theoretical calculations.

Question 2b: Definition of half-life (Half-life)
The HE performed 25 pp better than the HC in this question (HC obtained 46% and HE 71%). Similarly, the LE performed 18 pp better than the LC in this question (LC obtained 44% and LE 62%). These figures show that the ERGI laboratory practical activities had a very large effect on HE's and a noticeable effect on LE's understanding of half-life.

Question 3a: Experimental details of SHM: Relationship between the measured force and position of the mass (SHM)
The HE performed 1 pp better than the HC in this question (HC obtained 46% and HE 47%). On the other hand, the LC performed 9 pp better than the LE in this question (LC obtained 56% and LE 47%). These figures indicate that the ERGI laboratory practical activities had a small effect on HE's understanding and a reasonably large negative effect on LE's understanding of the experimental details of the SHM experiment.

Question 3b: Explaining two different methods of determining spring constant of a spring (Spring const.)
The HC performed 6 pp better than the HE in this question (HC obtained 52% and HE 46%). In contrast, the LE performed 7 pp better than the LC in this question (LC obtained 36% and LE 43%). These figures indicate that the ERGI laboratory practical activities had a reasonably large negative effect on HE's and a reasonable effect on LE's ability to explain the two different methods of determining the spring constant of a spring.

Question 4: Explain the working of the current balance (Current balance)
The HC performed 1 pp better than the HE in this question (HC obtained 39% and HE 38%). In contrast, the LE performed 1 pp better than the LC in this question (LC obtained 37% and LE 38%). These results show that the ERGI laboratory practical activities had a very small negative effect on HE's and a very small effect on LE's understanding of the working of the current balance.

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Question 5: Draw a transformer circuit diagram with voltmeters and ammeters (Transformer V and A)
The HE performed 5 pp better than the HC in this question (HC obtained 80% and HE 85%). In contrast, the LE performed 14 pp better than the LC in this question (LC obtained 63% and LE 77%). These figures indicate that the ERGI laboratory practical activities had a small effect on HE's and a noticeable effect on LE's ability to draw the circuit diagram of a transformer with voltmeters and ammeters.

Question 6: Determine amplitude and frequency of a signal displayed on an oscilloscope. (Oscilloscope)
The HE performed 8 pp better than the HC in this question (HC obtained 66% and HE 74%). On the other hand, the LE performed 2 pp better than the LC in this question (LC obtained 55% and LE 57%). These figures show that the ERGI laboratory practical activities had a reasonable effect on HE's and a very small effect on LE's ability to determine amplitude and frequency of a signal from an oscilloscope display.

Question 7a: Explain the function of the trigger of an oscilloscope. (Trigger 1)
The HE performed 4 pp better than the HC in this question (HC obtained 33% and HE 37%). In contrast, the LC performed 7 pp better than the LE in this question (LC obtained 25% and LE 18%). These figures indicate that the ERGI laboratory practical activities had a small effect on HE's and a reasonably large negative effect on LE's understanding of what the function of the trigger on an oscilloscope is.

Question 7b: What do the trigger level and trigger slope refer to? (Trigger 2)
There was no difference between the HE and the HC in this question (both HC and HE obtained 29%). On the other hand, the LC performed 25 pp better than the LE in this question (LC obtained 31% and LE 6%). These figures suggest that the ERGI laboratory practical activities had no effect on HE's and a very large negative effect on LE's understanding of what the trigger level and trigger slope refer to.

Question 8a: Linearize a graph of capacitive reactance vs. frequency (Linearization of graph).
The HC performed 10 pp better than the HE in this question (HC obtained 67% and HE 57%). In contrast, the LE performed 22 pp better than the LC in this question (LC obtained 35% and LE 57%). These figures indicate that the ERGI laboratory practical activities had a reasonably large negative effect on HE's and a very large effect on LE's understanding of linearizing graphs.

Question 8b: Plotting of a graph (Plotting graph)
The HE performed 1 pp better than the HC in this question (HC obtained 74% and HE 75%). In contrast, the LE performed 9 pp better than the LC in this question (LC obtained 69% and LE 78%). These results suggest that the ERGI laboratory practical activities had a very small effect on HE's and a reasonable effect on LE's ability to plot a graph.

Question 8c: Calculate C from graph (Calculate C from graph)
The HE performed 10 pp better than the HC in this question (HC obtained 34% and HE 44%). In contrast, the LC performed 13 pp better than the LE in this question (LC obtained 38% and LE 25%). These figures show that the ERGI laboratory practical activities had a

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reasonable effect on HE's and a noticeable negative effect on LE's understanding of calculating quantities from a graph.

4.4.2.2 Hands-on practical examination.

The marks obtained in the three experiments comprising the hands-on practical examination by control and experimental group students are shown in Table 4.9 and are presented graphically in Figure 4.12.

Figure 4.12 compares the average scores of the academically high and low achieving students in the control and experimental groups obtained from the hands-on practical examination after completion of the practical course. The academically high and low achieving students in the two groups performed best in the oscilloscope hands-on practical examination and the transformer hands-on practical examination. Good performance in the multimeters hands-on practical examination was shown by the high and low achievers in the two groups.

The oscilloscope hands-on practical examination

The HC and HE showed the best performance in this hands-on practical examination. The HC performed 4 pp better than the HE in this question (HC obtained 86% and HE 82%). Similarly, the LC performed 2 pp better than the LE in this question (LC obtained 78% and LE 76%). This shows that the ERGI laboratory practical activities had a small negative effect on HE's and LE's performance in these hands-on practical examination.

The multimeters hands-on practical examination

The HC and HE demonstrated a good performance in this hands-on practical examination. The HC performed 2 pp better than the HE in this question (HC obtained 55% and HE 53%). In contrast, the LE performed 11 pp better than the LC in this question (LC obtained 47% and LE 58%). These figures demonstrate that the ERGI laboratory practical activities had a small

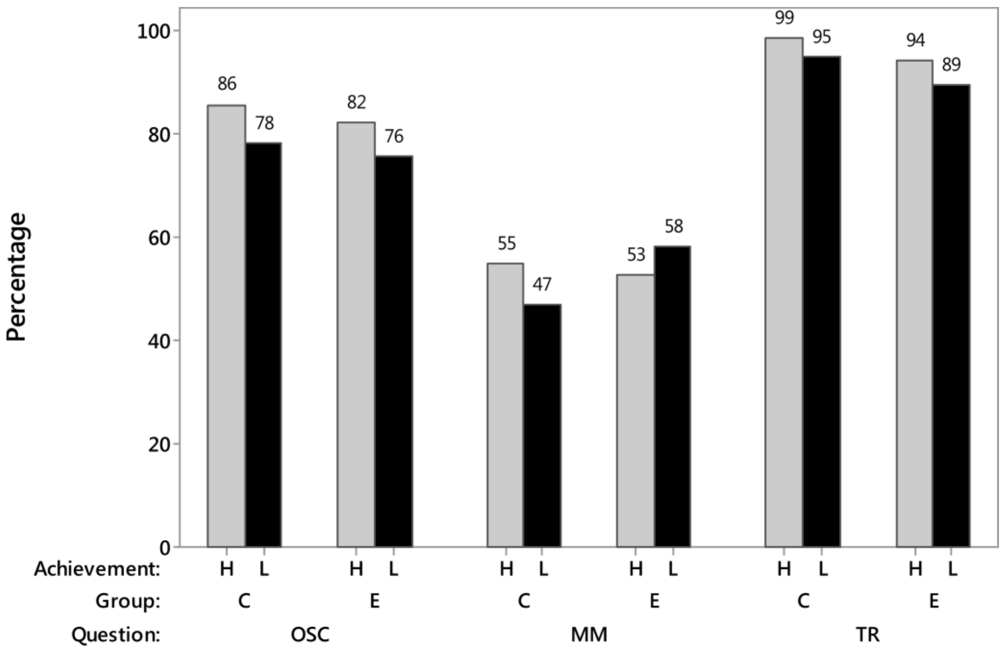

Figure 4.12 Average scores obtained by academically high and low achieving students in the hands-on practical examination questions, for the control and experimental groups.

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negative effect on HE's and a noticeable effect on LE's performance in this hands-on practical examination.

The transformer hands-on practical examination
The HC and HE demonstrated the best performance in this hands-on practical examination. The HC performed 5 pp better than the HE in this question (HC obtained 99% and HE 94%). Similarly, the LC performed 6 pp better than the LE in this question (LC obtained 95% and LE 89%). These figures show that the ERGI laboratory practical activities had a reasonable negative effect on HE's and a reasonable effect on LE's performance in this hands-on practical examination.

4.4.2.3 Effect of ERGI laboratory practical activities on the combined practical examination for the academically high and low achieving students

Table 4.10 covers the combined practical examination, i.e. written and hands-on practical examinations.The tendency of the ERGI laboratory practical activities to enhance students' knowledge of a concept, as tested by a question, was categorised as "successful", "partially successful", "neutral" and "unsuccessful", depending on the degree to which low and high achieving students showed an effect. The questions were classified in 4 groups, shown in Table 4.10. Concepts were deemed to be successfully taught by ERGI laboratory practical activities when an effect was seen for both high and low achieving students, for example in questions 2b, 1, 5, 6 and 8b respectively. Concepts on which questions showed an effect for LE while HE students showed a negative effect were deemed to be "favours L" (e.g. questions 8b and 3b as well as the multimeter hands-on practical examination) while those where HE showed an effect while LE showed a negative effect were considered "favours H" (e.g. questions 4 and 2a as well as the oscilloscope hands-on practical examination). Questions, for which both HE and LE showed a small effect, were considered "neutral" for example questions 7a, 8c, 3a, and 7b respectively as well as the transformer hands-on practical examination.

These results show that the ERGI laboratory practical activities assisted the high and low achieving students performing better in the content addressed by four of the selected questions (i.e. 2b, 1, 5, 6, and 8b) in the written practical examination. In the content addressed by questions 8a, B and 3b, ERGI laboratory practical activities assisted low achieving students more than the high achieving students in understanding the physics content. In the content addressed by questions 4, 2a and A, ERGI laboratory practical activities did show a small effect on students' understanding of the physics but ERGI laboratory practical activities was detrimental to students' ability to answer the content addressed by questions 7a, 8c, C, 3a and 7b respectively. It is concluded that the effectiveness of ERGI laboratory practical activities for some questions varied noticeably between the high and low achieving students.

Examining the results according to their level of the students' academic performance led to the insight that students only benefited from ERGI laboratory practical activities if the level of the questions were appropriate, i.e. the low achieving students seem to be stumped by the higher level questions, while the higher achieving students seem to be bored by the easy

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Table 4.10 Relationship between the ERGI laboratory activities on the scores of high and low achieving students grouped according to the successfulness of the ERGI practical in addressing learning of the corresponding content.

		Effect (E – C) (pp)	
Question	**Short summary**	**High achieving students**	**Low achieving students**
Favours both H and L			
2b	Definition of half-life	25	18
1	Proper connection of V and A meters	10	12
5	Draw a transformer circuit diagram with voltmeters and ammeters	5	14
6	Determine amplitude and frequency of a signal displayed on an oscilloscope	8	2
8b	Plotting of a graph	1	9
Favours L			
8a	Linearize a graph of capacitive reactance vs. frequency	–10	22
B	Multimeter hands-on practical examination	–2	11
3b	Explaining two different methods of determining spring constant of a spring	–6	7
Neutral			
4	Explain the working of the current balance	–1	1
2a	Explaining exponential decay and theoretical calculations	–4	–1
A	Oscilloscope hands-on practical examination	–4	–2
C	Transformer hands-on practical examination	–5	–6
Favours H			
7a	Explain the function of the trigger of an oscilloscope	4	–7
8c	Calculate C from graph	10	–13
3a	Experimental details of SHM: Relationship between the measured force and position of the mass	1	–9
7b	What do the trigger level and trigger slope refer to?	0	–25

questions. In both cases, learning was not effective. Some of the ERGI laboratory practical activities may have had shortcomings which should be investigated further.

4.4.2.4 Relationship between ERGI laboratory practical activities and the aggregate grades.

Table 4.9 and 4.11 as well as Figure 4.13 compare the average scores of the academically high and low achieving students in the control and experimental groups. Academically high achieving students in the experimental group demonstrated a better performance in the combined practical examination mark and theoretical year-end examination mark and aggregate grades than those in the control group.

The marks obtained by the students for the combined practical examination mark and theoretical year-end examination mark for the control and experimental group are shown in Table 4.11. In all cases the difference was either reasonable or small (3% or less).

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Comparing the results for the experimental and control groups (see Figure 4.13), it is clear that for each mark, the average scores of the academically high achieving students in the experimental group was higher than the corresponding value for those in the control group.

The marks obtained by the students for the combined practical examination and theoretical year-end examination for the control and experimental group are shown in Table 4.9 and 4.11. In the combined practical examination mark, the HE performed 1 pp better than the HC, while LE and LC got the same score of 64%. In the theoretical year-end examination mark the corresponding quantities were 2 pp and 3 pp. In all cases, there were small effects on students' performance, but since the differences are small it suggests that the ERGI laboratory practical activities did not have a significant effect on the performance of students in the combined practical examination.

4.5 Chapter summary

In this section a summary of results of the study is presented. The first section qualitatively analyses the general understanding of the seven aspects of NOS, followed by the quantitative analysis. Apart from the differences between control and experimental groups, differences between male and female students as well as academically high and low achieving students

Table 4.11 Relationship between ERGI practical activities on the scores of high and low achieving students on the scores in the combined practical examination and theoretical year-end examination.

	Average score (%)			
Short summary of question	HC	HE	LC	LE
Combined practical examination mark	67	68	64	64
Theoretical year-end examination mark	68	70	45	48

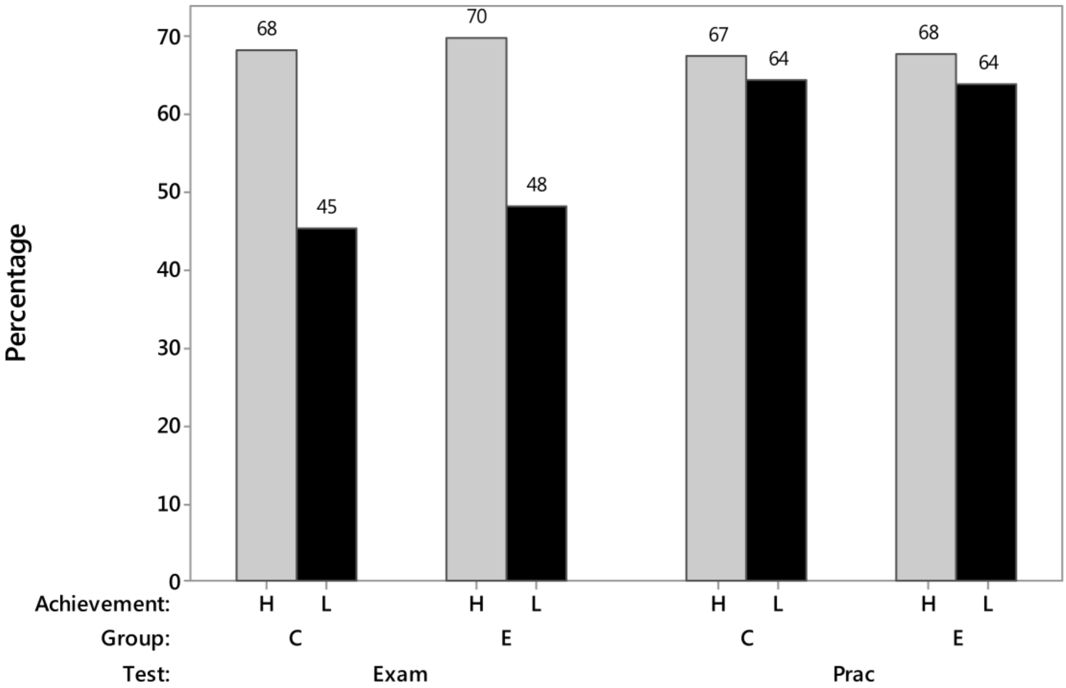

Figure 4.13 Average scores obtained by the academically high and low achieving students in the combined practical examination and theoretical year-end examination mark, for the control and experimental groups.

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are also reported. The second section summarises results on students' views about the practical course. The third section summarises the academic performance in the practical and theoretical year-end examinations, including differences between academically high and low achieving students.

4.5.1 Understanding of the Nature of Science

It was found that, generally, students in the experimental group displayed a slightly better understanding of the seven aspects of NOS compared to the students in the control group, leading to the conclusion that ERGI laboratory practical activities had an effect, though small, on the understanding of NOS. However, the overall effect of the ERGI laboratory practical activities was significant. It is therefore concluded that in the control group, females showed better understanding, and that ERGI laboratory practical activities impoved both groups' understanding of NOS, with the males showing a greater effect. Regarding differences between the low and high achieving students, the low achievers in the experimental group seem to have developed more informed views in many aspects of NOS compared to the high achieving students.

4.5.2 Students' views on the practical course

From the beginning of the practical course, the students in the experimental group showed an acceptance of the ERGI laboratory practical activities and no students asked to be dropped from the new practical activities.

Students in both control and experimental groups expressed similar views that the practical laboratory activities did encourage them to interrogate their views, encouraged team work amongst students and through group discussions problems could be easily resolved.
Both groups expressed the view that their thinking abilities and their understanding of different scientific theories were enhanced while engaged in the practical course. Moreover, students in both groups felt that the integration of the practical course with NOS explicit reflective guiding questions assisted them to change their attitudes towards science content and science learning. The use of guiding questions might have encouraged individual independence and assisted students in the discovery of science knowledge.

The experimental group students, who did the ERGI laboratory practical activities, felt that the practical activities were not difficult and that the practical activities aided their understanding and gave them more confidence in applying physics. Furthermore, they said they enjoyed the more interactive nature of the experiments. Students in the control group who performed recipe-based practical activities felt the importance of guiding instructions, which suggests that these students enjoyed step-by-step procedures when conducting practical activities.

Therefore, each group appreciated advantages of the method they used.

4.5.3 Academic performance

Overall, the experimental group performed 3 pp better than the control group in the theoretical year-end examination mark, while for the high achieving group this margin was 2 pp compared to 3 pp for the low achieving group. In the written practical examination the experimental group performed better in some questions but worse in others, with an insignificant overall difference. Furthermore, in some questions the differences between

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experimental and control groups were magnified for high achievers but reduced in other questions. In the hands-on practical examination there were no significant differences between experimental and control groups or between high and low achievers.

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Chapter 5: Discussion of the findings, conclusions and recommendations

In the preceding chapter, the results of tests and interviews were presented. This chapter discusses the findings of the current study, implications for science instruction, recommendations for future research studies and conclusions. The main objective of this study was to examine the influence of the ERGI laboratory practical activities on first-year physics students' understanding of NOS, attitudes towards science learning and academic performance. The sub-questions are discussed in terms of findings that are relevant to it.

In Section 5.1, the first research sub-question "*To what extent do guided inquiry-based laboratory activities promote understanding of the nature of science?*" is answered by the six findings in Sections 5.1.1 to 5.1.6. In Section 5.1.1, the first finding is discussed which involves the qualitative and quantitative results of the students' responses to the VNOS questionnaire and the FGI. Additionally, the students' understandings of the seven NOS aspects are evaluated in relation to the existing literature citing similar studies in South Africa and abroad. In Section 5.1.2, the second finding is discussed in which the effect of ERGI laboratory practical activities on the understanding of the various aspects of NOS is presented. In Section 5.1.3, the third finding is discussed which focuses on the differences between males and females in the control group regarding their understandings of NOS. Section 5.1.4 addresses the fourth finding which involves the differences in the effect of ERGI laboratory practical activities on males' and females' understanding of NOS. In Section 5.1.5, the fifth finding is discussed which focuses on the difference between academically high and low achieving students' understanding of NOS aspects in the control group. The next finding in Section 5.1.6 concerns the effect of the ERGI laboratory practical activities on VNOS understanding of high and low achievers.

In Section 5.2, the second research sub-question, "*To what extent do GI-based laboratory activities promote attitudes towards science learning?*" is answered by the seventh finding, which involves the views of students with specific reference to differences between the control and experimental groups after the completion of the practical course.

In Section 5.3, the third research sub-question, "*To what extent do guided inquiry-based laboratory activities promote academic performance?"* is addressed by the eighth and ninth findings in Sections 5.3.1 and 5.3.2, respectively. In Section 5.3.1, the effect of ERGI

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laboratory practical activities on academic performance is discussed. In Section 5.3.2, the difference in the effect of ERGI laboratory practical activities on the academic performance of high and low achieving students is discussed.

In Section 5.4, the overall research question is answered by the discussions taking into account students' understanding of NOS in Section 5.4.1, students' views on the laboratory work in Section 5.4.2 and students' academic performance in Section 5.4.3.

Section 5.5 summarises the discussion of the previous section. This will be followed by the discussions of implications regarding the current study in Section 5.6. Limitations of this study will be discussed in Section 5.7. Section 5.8 outlines the conclusion of the different sub-sections of the current study. This includes: Section 5.8.1, the difference in the understanding of NOS between the control and the experimental groups, Section 5.8.2, students' views on the practical course and Section 5.8.3, academic performance. Section 5.9 is a closing paragraph which addresses the original rationale and the problem statement of the current study.

Throughout the chapter results are compared to other studies selected from the literature. Since there are very few studies on NOS understanding that involve undergraduate physics students, it was decided to include studies involving secondary school science students and pre-service secondary school science teachers in the comparison. The reader is reminded that the present study differs from comparable studies in the sense that the control group was also given ERQs on NOS, similar to the experimental group. Only the laboratory sessions differed. The control group did recipe based practical activities, while the experimental group did inquiry-based practical activities. Furthermore, only post testing was conducted in the present study, while most other studies used pre- and post-testing. Therefore, the results from the control group, in the current study, are compared to pre-test results of the studies selected for comparison.

5.1 The first research sub-question:

To what extent do guided inquiry-based laboratory activities promote understanding of the nature of science?

The following findings in Sections 5.1.1 to 5.1.6 address the first research sub-question.

5.1.1 First finding: Understanding of the various aspects of NOS by students in the control group.

The first finding shows that, in the VNOS test administered at the end of the practical course, EN was the aspect the control group understood best, with 64% of students in the control group holding an informed view. Most of the students clearly expressed the view that science was empirical. Here their answers were well phrased. The most common misconception was that an experiment was the only way to gather empirical evidence to develop scientific knowowledge. Some students indicated that pure observation was a form of an experiment, which showed that they did not understand what an experiment was, but realised the value of pure observation.

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The control group demonstrated a reasonable understanding of two NOS aspects, namely OI and TN. As far as OI was concerned, 38% of the students had the informed view that different conclusions could be reached from the same observations of a single phenomenon due to scientists' different backgrounds. A common misconception was that inference is the direct interpretation of observations, i.e. that all inferences were obvious and that deep analysis was not required. Ultimately, students needed to understand that science involved a human interpretation of observations derived from natural phenomena. Chalmers (1999, p.7) maintained that "what observers see, the subjective experiences that they undergo, when viewing an object or scene is not determined solely by the images on their retinas but depends also on the experience, knowledge and expectations of the observer".

Regarding TN, 32% of the students showed informed views regarding different factors that may cause science knowledge to change. These include technological advancement, new methods of experimentation and expansion of scientific knowledge. One of the most common reasons for not considering students' views as informed was that the views did not express that scientific knowledge may also change due to evolution or revolution of scientific ideas. This agrees with the findings of Kuhn (1970) and Popper (1998). In addition, students often did not show a clear understanding of the level of certainty of scientists regarding the atomic structure, by indicating that the current atomic model will never change and that science knowledge is fixed.

The control group showed a poor understanding of the four NOS aspects IC, SM, TL and SC (with the percentage of students in the control group showing an informed view being 18%, 10%, 8% and 8%, respectively). Very few students showed informed views of TL, i.e. that a scientific theory is a broad explanation of observed natural phenomena, whereas a scientific law involves the statement of relationships between several variables in a controlled experiment or in an observation of a natural phenomenon. Many students held the misconception that there was a hierarchical relationship between theories and laws, by believing that a scientific theory will later change into a scientific law. This means that students believe that a theory is tentative and a law is certain.

One of the most common misconceptions was due to misunderstanding the interaction of humanity with science, especially regarding the influence of social and cultural values as well as imagination and creativity. Scientific knowledge is believed to be the absolute truth that can never be influenced by IC and SC.

Few students had an informed view that imagination and creativity are used in all stages of scientific investigations (i.e. planning and designing, collection of data and data analysis). Most students held the misconception that IC might be used in some stages of the scientific investigation only, although some students demonstrated the misconception that scientists should not use IC at all, as this would interfere with the data gathered in scientific investigations which were considered to be factual and empirically based.

Only a few students demonstrated the informed view that science knowledge was influenced by social and cultural values due to scientists' different cultural beliefs, different religious beliefs, different thinking capabilities, technological advancement and different scientific methods. One common misconception amongst many students was that scientific knowledge was factual as it was supported by empirical evidence and consequently, it could not be

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influenced by social and cultural beliefs. This contrasted with the correct view that the interpretation of observations itself was influenced by SC.

The poor understanding of TL, SC and IC agrees with Lederman *et al*. (2002). To develop informed views of these aspects, it is essential to realise that science is tentative and that science is influenced by several factors including technological innovations, societal, political and economic situations. The students generally failed to understand that science involved a human interpretation of observations derived from natural phenomena. Human interpretation is guided by certain theoretical understandings (theory-laden) and is influenced by SC and IC.

In the SM aspect, very few students demonstrated an informed view that scientists use a variety of scientific methods guided by their different thinking styles, cultural beliefs, and different expertise in their fields of research. Most students believed that if scientists use various scientific methods, they must arrive at the same results and conclusions. Furthermore, only a small number of students indicated that scientists could work according to more than one scientific method. As discussed earlier, the most common misconception was that an experiment was the only way of gathering empirical evidence that supported scientific knowledge. Some students indicated that pure observation was a form of an experiment which showed that they did not understand what an experiment was, but realised the value of pure observation.

Qualitatively, the misconceptions observed agreed with the literature as discussed in Section 2.3 of Chapter 2. The quantitative results for the control group's NOS understanding are firstly compared to similar South African studies and secondly to international studies below.

Comparison to South African studies

Table 5.1 compares the current results to that obtained in three comparable studies by Baloyi, Nordhoff, Meyer, Gaigher and Braun (2014), Dekkers (2006) and Vhurumuku (2010). The results from the study by Dekkers were compared to the findings in the current study because inquiry-based approach combined with reflective learning had been used. Similar approach was used in the current study that explored the effect of GI combined with ERQs on NOS understanding. There are few South African studies, and the ones listed were the closest comparable studies. In the discussion of results, the findings of the control group's understanding of NOS aspects in the current study will be compared to the pre-test results of these studies.

The students in the study by Vhurumuku (2010) showed almost no understanding of NOS in the pre-test. This is difficult to explain given that the study has been conducted amongst BSc undergraduate students. In the remaining two studies, EN was relatively well understood, but

Table 5.1 Comparison between the results of the control group in the current study and other South African studies

		Informed view of NOS aspects (%)						
References	**Sample**	**EN**	**OI**	**TN**	**IC**	**SM**	**TL**	**SC**
Current study	First year BSc physics students	64	38	32	18	10	8	8
Baloyi *et al.* (2014)	Top performing Grade 10 students	31	22	32	19	19	6	25
Dekkers (2006)	High school learners (Gr 7 – 11).	42	–	–	65	54	–	–
Vhurumuku (2010)	Undergraduate BSc students	0	–	0	–	6	0	–

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not as well as in the present study. Other notable differences were that the learners studied by Dekkers (2006) performed much better in IC and SM than in the other three studies (including the current study) and learners in the study by Baloyi *et al.* (2014) performed much better in SC than the students in the current study. There does not seem to be a clear reason for these differences, but differences in criteria for evaluation may also have played a role.

The understanding of NOS by the students in the current study followed a different trend than that observed in other South African studies. EN was well understood followed by OI and TN, which were reasonably well understood. Students in the current study seemed to have a notably worse understanding of SM and SC, but a better understanding of EN (and possibly OI) when compared to Baloyi *et al.* (2014) and Dekkers (2006).

In all the studies, TL attracted the lowest score, and was clearly the least understood aspect of NOS.

Comparison to international studies

The results in the current study were compared to four international studies where the researchers targeted similar NOS aspects than those covered in the current study. As mentioned earlier, the results for the control group will be compared with the pre-test results of these studies.

The results of the four international comparable studies by Çıbık, (2016); Celik and Bayrakceken (2012); Baraz (2012) and Akerson *et al.* (2007) are summarised in Table 5.2. Similar to the comparison with other South African studies, the result that EN was the best understood aspect of NOS (64%) was in contrast with the one international study that also measured understanding of this NOS aspect (17%). The performance in EN by students in the current study may be attributed to the use of explicit-reflective NOS questions and physics laboratory activities.

In two of the international studies OI and TN were poorly understood, in agreement with all three South African studies, but in contrast with the current study where both OI and TN were reasonably well understood. The exception was the study by Akerson *et al.* (2007), where K-6 teachers showed a better understanding of OI (47%) and a much better understanding of TN (90%). Celik *et al.* (2012) found a reasonably good understanding of OI but a poor understanding of TN.

For IC, the percentage of informed views in the current study was 18%, which put it at the

Table 5.2 Comparison between the results of the control group in the current study and similar international studies.

References	Sample	Informed view of NOS aspects (%)						
		EN	**OI**	**TN**	**IC**	**SM**	**TL**	**SC**
Current study	First year BSc physics students	64	38	32	18	10	8	8
Çıbık (2016)	pre-service science teachers	–	7	6	6	3	7	5
Celik *et al.* (2012)	prospective science teachers	–	36	3	12	–	0	15
Baraz (2012)	pre-service science teachers	17	22	11	56	–	50	22
Akerson *et al.* (2007)	K–6 teachers	–	47	90	32	–	–	32

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lower end of the range of international studies, which varied widely from 6% to 56% in respect of informed views.

In agreement with the current study, most international studies found a poor understanding of SM and TL, the exception being Baraz (2012), where pre-service teachers showed a good understanding of TL.

SC, which was the worst understood aspect in the current study, was better understood in 3 out of the 4 international studies. SC is one of the NOS aspects which was generally poorly understood in South African studies but better understood in international studies. However, the poor understanding of SC in South African studies may be attributed to the lack of emphasis on the role played by social and cultural values in the development of knowledge in science instruction.

In summary, similar to the trend observed in South African studies, literature shows that the subjects in the international studies generally displayed a poor understanding of most aspects of NOS (EN, OI, TN, IC, SM and TL) (Chen, 2006; Lederman, 1992, 2007; McComas, 1998). Depending on the sample, students seem to have a good understanding of some aspects and worse of others, however, no clear pattern seems to emerge. Compared to the South African and international tests, the students in the current study performed particularly well in EN and particularly poorly in SC.

5.1.2 Second finding: Effect of ERGI laboratory practical activities on understanding the various aspects of NOS

The overall percentage of informed views shows that students in the experimental group outperformed the students in the control group (10 pp, $p = 0.008$). The results suggest that the ERGI laboratory practical activities had a noticeable effect on experimental group's understanding of TN, IC, and TL (p values of 0.178, 0.115 and 0.067 respectively), a reasonable effect on experimental group's understanding of SC, SM and EN (p values of 0.220, 0.247 and 0.577 respectively), and a small effect on experimental group's understanding of OI ($p = 0.685$).

Although all p-values are larger than the cut-off of 0.0071(see Section 3.7.6), the p-values for TN, IC and TL are the smallest with values of 0.178, 0.115 and 0.067, respectively, suggesting that we could have found a statistically significant difference when taking a different sample of students, which could indicate that ERGI laboratory practical activities had a noticeable effect on experimental group's understanding of TN, IC, and TL. The remaining p-values are larger with values of 0.220, 0.247, 0.577 and 0.685 for SC, SM, EN and OI, respectively, indicating that ERGI laboratory practical activities had a small effect on the understanding of these aspects.

From these results, it is concluded that the experimental group students' overall understanding of NOS showed a statistically significant improvement resulting from the ERGI laboratory practical activities compared to control group students doing the traditional recipe-based practical activities.

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Though the improvement in EN is small, both groups showed a good understanding of EN. This may indicate that the ERQs given to both groups supported the understanding of EN.

Comparison to similar South African studies

The results of the three comparable studies by Vhurumuku (2010), Baloyi, Meyer and Gaigher (2016), and Dekkers (2006) are summarised in Table 5.3. Two out of the three studies showed a much larger effect in EN than the current study. These two studies both used reflective strategies. The large improvement therefore suggests that reflective strategies improve the understanding of EN. For this reason, a small effect was observed in the current study, as both the control and experimental groups were given ERQs and both performed well in EN, resulting in a small effect attributed to the inquiry-based laboratory activities.

Another notable result is that the students, studied by Vhurumuku (2010), showed a much greater effect in the understanding of TN, TL and SM compared to the other three studies (including the current study). Also, learners in the study by Baloyi *et al.* (2016) showed a much greater effect in OI compared to students in the current study. The study by Dekkers (2006) involved an intervention similar to that in the current study and also showed similar improvement in the understanding of NOS. On the other hand, the study by Baloyi *et al.* (2016) did not teach NOS directly and showed a smaller effect. This comparison supports literature on the value of explicit instruction on NOS.

Comparison to similar international studies

The results in the current study were again compared to the results of the same four selected international studies (Çıbık, 2016; Celik & Bayrakceken, 2012; Baraz, 2012 and Akerson, Hanson & Cullen 2007) as discussed in Section 5.1.1. These studies had a NOS intervention and there were comparisons between control and experimental groups where pre-post tests were administered to both groups. As discussed earlier, consideration was again given to studies that focused on secondary science students and pre-service secondary science teachers. In the discussion of results, the differences in performance on different aspects (i.e. change in scores on different aspects) from control group to experimental group after completion of the ERGI laboratory practical activities in the current study will be compared to the results of the international studies. The detailed analysis of results in the literature can be found in the Appendix L.

Table 5.3 Comparison between the effect of ERGI laboratory practical activities on students in the current study and similar South African studies.

		Effect on understanding NOS (E – C) (pp)						
Reference	**Type of intervention**	**TN**	**IC**	**TL**	**SC**	**SM**	**EN**	**OI**
Current study	Explicit-reflective questions & guided inquiry laboratory activities	16	15	14	9	9	6	4
Vhurumuku (2010)	Explicit-reflective Nature of Science Course	84	–	32	–	36	16	–
Baloyi *et al.* (2016)	Science enrichment programme (inquiry based), no specific NOS	–9	11	1	–3	1	–2	28
Dekkers (2006)	Inquiry and reflection	–	16	–	–	6	20	–

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Table 5.4 Comparison between the effect of ERGI laboratory practical activities on students in the current study and similar international studies**.**

		Effect on understanding NOS (E – C) (pp)						
References	**Type of intervention**	**TN**	**IC**	**TL**	**SC**	**SM**	**EN**	**OI**
Current study	Explicit-reflective questions with either traditional laboratory activities or guided inquiry laboratory activities.	16	15	14	9	9	6	4
Çıbık (2016)	Project-Based History and NOS training and Conventional Method	15	14	14	18	21	–	15
Celik *et al.* (2012)	Explicit NOS instruction	72	17	58	25	–	–	49
Baraz (2012)	Metacognitive strategies embedded in explicit–reflective NOS instruction	22	11	23	11	–	30	25
Akerson *et al.* (2007)	Metacognitive strategies NOS instruction	10	10	–	31	–	–	21

The effects of the intervention in the four comparable studies by Çıbık, (2016), Celik *et al.* (2012), Baraz (2012) and Akerson *et al.* (2007) are summarised in Table 5.4. All four international comparable studies showed a larger effect in SC and OI than the current study. The reasons for this are not clear.

Similarly to the comparison with other South African studies, the international study with only explicit NOS instruction (Celik *et al.,* 2012) showed a noticeably larger effect than the other studies. The effects of the interventions in the remaining three studies were mostly similar to that obtained in the current study. This comparison suggests that explicit instruction is the most effective strategy to improve understanding of NOS.

5.1.3 Third finding: Difference between males' and females' understanding of NOS in the control group

The overall percentage of informed views shows that females outperformed the males in the control group with a small margin of 4 pp. The females outperformed the males in EN (31pp), SC and IC (6pp each), OI (4pp) as well as in TN (1pp). In contrast, the males had an advantage over the females in SM (12pp) and TL (9pp). These remarkable gender differences are obscured by the overall score, which is only slightly different for males and females. For neither in the overall score (p = 0.62) nor in any of the sub-categories was the difference between males and females statistically significant.

From these results, there are indications that males and females in the control group, on average, have different abilities in understanding different aspects of NOS. A literature search found no studies on NOS that focused on gender differences, except a study that was conducted in South Africa by Baloyi *et al.* (2014). Baloyi *et al.* (2014) found a very small difference of less than 1 pp between the average scores of males and females, but also observed larger differences in the individual aspects, with the largest difference being in TL, where males scored better and in IC where females scored better. It can be concluded that though the overall result of the current study support findings that understanding of NOS is not gender biased (Lederman *et al.,* 2002). Further investigation is required to establish possible gender effects on aspects of NOS.

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Research shows that gender typing encourages the forming of gender-role identity and integrates masculinity and femininity in a person's self-concept and gender identity (Knafo, Iervolino & Plomin, 2005; Spence, 1993). Other studies demonstrated that stereotypes in many societies encouraged maths and science as typically male domains and considered females as less capable in these domains (Haussler & Hoffmann, 2002; Nosek, Smyth, Sriram, Lindner, Devos, Ayala, & Greenwald, 2009; Szymanowicz & Furnham, 2011). It was established, from a theoretical review of the effect of motivation in describing gender differences in academic attainment and achievement that boys and girls persist to differ with regards to traditional gender role stereotypes, with boys showing a higher ability and interest in science and mathematics than girls (Meece, Bower Glienke & Burg, 2006).

TL, OI and SM are some of the more challenging aspects of NOS (Lederman *et al.*, 2002). The understanding of these aspects (TL and SM) by males in the current study may be enhanced by being able to visualise the process of generating scientific knowledge, as research has shown that boys outperform girls on tasks relying on spatial orientation and visualisation skills (e.g. Halpern, Aronson, Reimer, Simpkins, Star & Wentzel, 2007; Voyer, 1996; Voyer, Boyer & Bryden, 1995). In addition, the good performance by males in these aspects may be due to the higher self-efficacy (Bandura, 1995; Woolfolk, 2001) amongst boys towards science learning than females (Britner & Pajeras, 2006).

Females in the current study showed a better performance in EN, SC, IC, OI and TN, as the understanding of these aspects may be enhanced by social skills and there may also be an advantage in respect of the female students' better writing skills. Research has further shown that girls outscore boys on tasks relying on verbal and writing skills, memory and perceptual speed (e.g. Halpern *et al.*, 2007; Kimura, 2002). Moreover, stereotypical beliefs pertaining to gender roles and social expectations may have encouraged females to have more positive attitudes towards languages and reading (Hoffmann, 2002; Meece *et al.*, 2006).

5.1.4 Fourth finding: Differences in the effect of ERGI laboratory practical activities on male and female students' understanding of NOS

The effect of ERGI laboratory practical activities on male and female students' understanding of NOS is shown in Table 5.5.

The overall percentage of informed views shows an effect due to the ERGI laboratory practical activities of 11 pp and 7 pp for the male and female students, respectively, i.e. a difference of 4 pp. It is concluded that the ERGI laboratory practical activities influenced both males and females, however, the effect was slightly larger on the male students' understanding of NOS than on the females' understanding of NOS and the effect on the overall score of NOS was very small. It is interesting to note that, in the experimental group, both genders obtained the same overall score.

As far as individual NOS aspects are concerned, males showed a reasonably large effect in all aspects of NOS. Females showed a positive effect in 5 out of 7 NOS aspects, but a marked negative effect in EN. The major difference between the effect on males and females was in the IC aspect, where females showed a substantially larger effect and EN where the males' performance was enhanced, while the females showed a negative effect. In the case of TN, the effect on females was also larger than on males. As discussed earlier, the larger effects in

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Table 5.5 Differences in the effect of ERGI laboratory practical activities on male and female students' understanding of NOS

	Informed (%)				Effect (C – E) (pp)		Difference in effect
NOS aspect	MC	ME	FC	FE	(ME – MC)	(FE – FC)	[(ME – MC) – (FE – FC)]
TN	32	45	33	55	13	22	–9
EN	58	68	89	75	10	–14	24
TL	9	27	0	17	18	17	1
OI	36	44	40	31	8	–9	17
IC	16	24	22	50	8	28	–20
SC	7	19	13	17	11	4	7
SM	12	23	0	8	11	8	3
Overall	24	35	28	35	11	7	4

IC and TN may be attributed to the female students' better language skills (Meece *et al.*, 2006; Yarborough & Johnson, 1980).

In a literature search, no studies were found that addressed the effects of interventions on males' and females' understanding of different NOS aspects. However, a wealth of literature on the effects of interventions on performance of males and females in science exists.

Some studies have shown that the use of an interactive approach promoted science learning for both males and females (Mazur, 1997; McDermott & Schaffer, 2002), while others suggested that females may benefit more than males (Laws, Rosborough & Poodry, 1999; Schneider, 2001). In a study by scholars at Harvard University it was shown that an interactive approach eradicated the gender gap in an introductory physics course, with females showing the strongest effect and attaining scores after the course approximately equal to those of the males (Lorenzo, Crouch, & Mazur, 2006).

In another study, Wolf and Fraser (2008) showed that males and females performed differently in traditional and inquiry-based laboratory activities. Males showed a better academic performance in respect of inquiry instruction. Females seemed to have benefited more from non-inquiry approaches in respect of enhanced attitudes towards science, co-ordination of classroom tasks, and collaboration.

Through the ERGI laboratory practical activities, males and females were provided with various opportunities to investigate and justify their claims. Through this collaboration and interaction males may benefit from the females' thought processes, whereas females may also benefit from the males' confidence (Lee, 2003). From Table 5.5 it is seen that in the control group, females had a 4 pp advantage in their overall score, while in the experimental group, both groups had the same score. Therefore, the current study supports literature indicating that active engagement in science learning tends to diminish gender effects.

5.1.5 Fifth finding: Difference in the understanding of NOS aspects between the academically high and low achieving students in the control group

The overall percentage of informed views shows that the low and high achievers in the control group showed similar understanding in the VNOS test (see Table 5.6).

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The figures indicate that high achievers had a better understanding of TN, SC, IC and SM only. On the other hand, the low achievers had a better understanding of OI, EN, and TL. Furthermore, TL, SC and SM were poorly understood by both groups. Although there were no differences in the overall understanding of NOS between the high achievers and low achievers in the control group, there were differences in some aspects. However, there seemed to be no discernible pattern in these differences. The *p*-values also showed that none of these differences were statistically significant.

From these results, it was concluded that there were no differences in overall understanding between the academically high and low achievers' in respect of the informed understanding of NOS aspects. In a study by Baloyi *et al.* (2014) with 100 grade 10 learners attending a science enrichment programme, no correlation was found between academic performance and NOS understanding.

A literature search found no other studies comparing NOS understanding of academically high and low achievers.

5.1.6 Sixth finding: Difference in the effect of ERGI laboratory practical activities on the academically high and low achieving students' understanding of NOS

The effect of ERGI laboratory practical activities on the academically high and low achieving students understanding of NOS is shown in Table 5.6.

Overall, in the control group, the high and low achieving students performed the same. In the experimental group, both groups showed a reasonably large increase in their scores though the low achievers performed slightly better. It therefore seemed that the low achieving students benefited slightly more from ERGI laboratory practical activities. Both the high and low achievers showed an effect in 6 out of the 7 NOS categories, however none of the differences were statistically significant. The largest effects were found for the low achievers in TN and SC. The explanation for the negative effect in OI could be that it is a difficult concept, perhaps confusing for low achievers.

It is suggested that this difference in performance might be ascribed to the GI questions being aimed at supporting lower achieving students. This was done to ensure that most students would be able to perform the practical activities. High achieving students could possibly foresee the answers and therefore benefited less from the guidance. For example, SC showed

Table 5.6 Differences in the effect of ERGI laboratory practical activities on academically high and low achieving students' understanding of NOS.

	Informed (%)				Effect (E – C) (pp)		Difference in effect
NOS aspect	HC	HE	LC	LE	HE – HC	LE – LC	[(HE – HC) – (LE – LC)]
TN	38	53	25	47	15	22	–7
EN	67	69	71	75	2	4	–2
TL	8	27	14	25	19	11	8
OI	33	38	57	47	5	–10	15
IC	23	40	21	38	17	17	0
SC	17	20	0.0	25	3	25	–22
SM	15	13	13	25	–2	12	–14
Overall	29	36	29	40	7	11	–4

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a larger effect for low achievers but small effect for the high achievers. The exception to the rule was the understanding of the differences between theories and laws, where the high achieving students demonstrated a better understanding than the low achieving students. As mentioned earlier for OI, TL is a more complex concept and therefore it was possibly grasped better by the high achieving students, who therefore showed a better performance.

As discussed earlier, no studies were found in the literature that addressed the effects of interventions on high and low achieving students' view on NOS.

5.1.7 Synthesis of the findings related to the first sub-question

The control group showed a good understanding of EN, a reasonable understanding of OI and TN, but a poor understanding of IC, SM, TL and SC. It was found that generally students in the experimental group performed 10 pp better than those in the control group in all of the seven aspects of NOS, with a noticeable effect in TN, IC and TL as well as a small effect in SC, SM, EN and OI. The difference in overall understanding of NOS, between the experimental and control group, was statistically significant with p = 0.008 leading to the conclusion that ERGI laboratory practical activities had a statistically significant effect on the understanding of NOS, when used in conjunction with ERQs on NOS instead of the traditional recipe based laboratory activities.

In the control group**,** there was only a very small difference in the overall score between genders and academically high and low achieving students, though there were differences in individual NOS aspects. However, EN and OI showed large exceptions for gender and achievement effects respectively.When analysed per gender, females showed a positive effect in 5 out of the 7 NOS aspects, while males showed a positive effect in all the 7 NOS aspects. High and low achieving students showed positive effects in 6 of the 7 NOS aspects, with overall effects of 7 pp and 11 pp, respectively, at the end of ERGI laboratory practical activities, while male and female students showed effects of 11 and 7 pp respectively. Gender and academic achievement had only a very small influence on the effect of ERGI laboratory practical activities on the overall NOS score.

5.2 The second research sub-question:

To what extent do guided inquiry-based laboratory activities promote attitudes towards the laboratory work?

The following finding, Section 5.2.1, is relevant to addressing the second research sub-question.

5.2.1 Seventh finding: Students' views on the ERGI and traditional laboratory practical activities

Qualitatively, it seems that both groups experienced the practical course beneficial to their learning, and felt that their confidence was enhanced. Both groups, as documented in Section 4.5.2, suggested that the practical activities exposed them to new situations and contributed to their understanding of the application of physics to real experiments.

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Norman and Schmidt (2000) demonstrated that Problem Based Learning provided a thought-provoking, encouraging and enjoyable approach to learning. Bonwell and Eison (1991) concluded from the research on active learning, that it promoted better attitudes and thinking skills in students.

In addition, students in the experimental group could see the advantage of ERGI laboratory practical activities over recipe based activities. However, from some of the answers it was clear that where students in the experimental group showed growth and overcame their need for recipe-like instructions, the control group appreciated recipe-based instructions, possibly because they had no other experiences.

There is overwhelming evidence in the literature indicating that the inquiry-based laboratory activities promote collaborative reflective practices and enhance cognitive development as well as positive attitudes towards science learning (Beichner *et al.,* 2000; Desouza *et al.,* 2003; Hofstein *et al.,* 1982; Lazarowitz *et al.,* 1994; Lunetta, 1998; McReary *et al.,* 2006; Oliver-Hoyo & Allen, 2005). Koballa and Glynn (2007, p.94-95) attested that, "science learning experiences that are fun and personally fulfilling are likely to foster positive attitudes and heightened motivation toward science learning and lead to improved achievement. Approaches to positively affecting student attitudes include instruction that emphasizes active learning and the relevance of science to daily life".

In contrast, it is reported in the literature that the recipe-based laboratory practical activities are procedural and cannot promote students' reasoning and thinking skills (e.g. Banchi & Bell, 2008; McDermott, 1991, 1993). The results in the current study supported this claim as discussed below.

Students demonstrated during the FGI that, each group (i.e. control and experimental groups) appreciated the advantages of the method they used. i. e. the control group appreciated the rigid approach, while the experimental group appreciated the freedom guided inquiry afforded them. This is supported by the quantative results in this study (Section 4.2.1) which show that the students that performed ERGI laboratory practical activities appreciated the role of imagination and creativity more than the control group. This is in agreement with literature that states that students that performed GI activities tended to view science as an imaginative and creative human endeavour, while those that performed recipe-based practical activities believed science was a fixed body of knowledge to be discovered experimentally and supported a rote means of learning science (e.g. Hammer, 1994; Songer & Linn, 1991; Wallace *et al.,* 2003).

From the results in the current study, it was concluded that although students who performed recipe-based practical activities felt the need for guiding instructions, the students in the experimental group demonstrated a shift in their views about learning, confidence and thinking skills when they did GI-based practical activities.

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5.3 The third research sub-question:

To what extent do guided inquiry-based laboratory activities promote academic performance?

The findings in Sections 5.3.1 and 5.3.2 are relevant in addressing the third research sub-question. Section 5.3.1 addresses the effect of ERGI laboratory practical activities on academic performance, including the combined practical examination (written practical examination, plus the hands-on practical examination) and theoretical year-end examination marks. Section 5.3.2 compared the effect of ERGI laboratory practical activities on the academic performance of high and low achieving students, which led to further insights.

5.3.1 Eighth finding: Effect of ERGI laboratory practical activities on academic performance

From the results, it seems that the ERGI laboratory practical activities had a small impact on students' performance in the combined practical examination and almost no significance on their performance in the theoretical section of the course.

5.3.1.1 Performance in the combined practical examination

The control group performed 4 pp better than the experimental group in the written practical examination, while there was no difference in the hands-on practical examination. In the combined practical examination, the control group performed 2 pp better. These results suggest that the ERGI laboratory practical activities had a very small negative effect on students' performance.

It was noted that, while some activities in the ERGI laboratory practical activities showed a positive effect on students' performance in the relevant question in the written practical examination, there were others where the effect was negative. For instance, ERGI laboratory practical activities had reasonably large negative effect on the experimental group's understanding of calculating quantities from a graph. The possible explanation could be that some ERGI laboratory practical activities were more successful for answering some questions. The explanations for these results are beyond the scope of the current study and this need to be investigated further in the future studies.

5.3.1.2 Theoretical year-end examination

In the theoretical year-end examination mark, the experimental group performed 3 pp better than the control group. This indicates that the ERGI laboratory practical activities might have had a small effect on students' performance, but since the difference is so small, it is concluded that the ERGI laboratory practical activities did not have a significant effect on the performance of students in the theoretical year-end examination.

At the end of each practical session students in both groups had to answer an explicit reflective question relating the practical activity to NOS. A literature search indicated that, in agreement with a comment by Schwartz (2013), there were no similar studies reported that integrate NOS within science subject matter, or investigated the effect of the combination of explicit reflective instruction and GI on the understanding of science content.

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Similar to the current study there are numerous studies that found that inquiry based activities do not improve academic performance. Research studies on problem-based learning with medical students (Albanese, & Mitchell, 1993; Vernon, & Blake, 1993) showed that the performance on standardised examinations decreased marginally. While research studies conducted by El-Nemr (1980) and Lott (1983) have shown that inquiry-based approaches had a small positive effect on students' academic achievement in examinations.

In contrast, Bunterm, Lee, Kong, Srikoon, Vangpoomyai, Rattanavongsa and Rachahoon. (2014) investigated the effects of guided vs. structured inquiry on secondary students' learning of science. The results showed that students in the guided-inquiry groups performed better in both science content knowledge and process skills than students in structured inquiry.

5.3.2 Ninth finding: Difference in the effect of ERGI laboratory practical activities on low and high achievers' academic performance

5.3.2.1 Performance in the combined practical examination:

In the written practical examination the high achieving students showed a 2 pp effect, while low achieving students showed –1 pp effect. In the hands-on practical examination high achieving students showed a – 4 pp effect, while low achieving students showed 2 pp effect. In the combined practical examination, the high achieving students showed 1 pp effect, while low achieving students showed no effect. Therefore, in the hands-on practical and the combined practical examination, the ERGI laboratory practical activities had a small negative effect on the high achieving students' performance and a small effect on the low achieving students. However, since the differences were small it was concluded that the low and high achieving students benefitted equally from the ERGI laboratory practical activities as far as the written and combined practical examination marks were concerned. There seemed to be a small differential effect in the hands-on practical examination, where the high achieving students showed a small effect, 1 pp than the low achieving students.

It was also observed that, while some activities in the ERGI laboratory practical activities showed a positive effect on students' performance in some questions in the written practical examination, there were others where the effect was negative. When the high and low achieving students were analysed separately, it became clear that the performance of the students in some questions varied significantly and it seemed that some activities were more appropriate to high achieving students than low achieving students.

The explanations for these results are beyond the scope of the current study and these needs to be investigated further in the future studies.

5.3.2.2 Theoretical year-end examination:

In the theoretical year-end examination mark, the high achieving students showed an effect of 2 pp, while for low achievers a 3 pp effect was found. This indicated that the ERGI laboratory practical activities might have had a small effect on students' performance, but since the difference was so small, it was concluded that the ERGI laboratory practical activities did not have a significant effect on the performance of students.

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A literature search indicated that there were no studies that integrated NOS within science subject matter in relation to the variation in academic performance between academically high and low achieving students.

5.4 Overall research question in terms of the theoretical framework

To what extent does explicitly reflective guided inquiry-based instruction in practical laboratory activities influence the outcomes achieved in a first-year physics course?

In Sections 5.4.1, 5.4.2 and 5.4.3, the results from the sub-questions are combined to address the overall research question.

5.4.1 Effect of ERGI laboratory practical activities on understanding of NOS

It was found that students in the experimental group generally displayed a slightly better understanding of the seven aspects of NOS than students in the control group, leading to the conclusion that ERGI laboratory practical activities had an effect, though small, on the understanding of NOS. It was found that the difference in overall understanding of NOS between the experimental and control group was statistically significant with p = 0.008. Gender and academic achievement had a negligible influence on the effect of the ERGI laboratory practical activities in the understanding of NOS. These results support what was initially predicted by the conceptual framework that the combination of PbI and ERQs could bring about better understanding of NOS aspects.

5.4.2 Effect of ERGI laboratory practical activities on students' views on laboratory work

At the start of the practical activities, the students did not show a significant resistance to the GI approach. After the practical course, students in the experimental group expressed views that the ERGI laboratory practical activities encouraged collaboration, equipped them with thinking and problem-solving skills and assisted them to understand the relationship between scientific knowledge and real-life experiences and that they now preferred the GI approach. Interestingly, students in the control group stated that they preferred the clear instructions provided by the traditional practical activities. These results further support what was initially predicted by the conceptual framework that the combination of PbI and ERQs could bring about better understanding of NOS aspects which could promote collaborative learning skills amongst students.

5.4.3 Effect of ERGI laboratory practical activities on academic performance

Overall, there were only very small differences observed between the groups in their academic performance in the combined practical examination and the theoretical year-end examination. Further analysis of some questions showed large differences in their effect on high and low achieving students, showing that some activities were more effective for high achieving students while others were more effective for low achieving students. These results need to be investigated further in the future studies. These results are incontrast what was initially predicted by the conceptual framework that the combination of PbI and ERQs could

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bring about better understanding of NOS aspects which could enhance conceptual development of physics concepts and academic performance.

5.5 Discussion

Control group's views of NOS

The current study shows that relatively few students in the control group showed informed views of the targeted NOS aspects. The students showed a good understanding of EN, OI and TN but a poor understanding of TL, IC, SC and SM.

Despite the control group being asked ERQs on NOS, their understanding of NOS was poor. This demonstrated that certain beliefs about science knowledge may not be easily changed because they are linked with other beliefs in their belief system (Richardson, 1996).

It is gratifying to report that, in the present study, females slightly outperformed males, with approximately the same performance in each individual aspect of NOS. The results also showed that the low achievers and the high achievers in the control group presented a similar NOS understanding. As discussed earlier, these results agree with literature.

In contrast with similar international studies, students from South Africa displayed a better understanding of the empirical nature of science compared to all the other aspects of NOS (see the second finding). A possible reason could be the effect of the many curriculum changes from the Curriculum 2005 policy (Department of Education, 2005) to RNCS (Department of Education, 2006) and NCAPS (Department of Education, 2012). As discussed earlier in Section 1.2, a consistent feature in the curriculum transformations has been to emphasise the development of scientific literacy by conducting scientific investigations and practical work, focusing mainly on EN and TN. This was especially prominent in RNCS and NCAPS. During each curriculum change, teachers had to attend workshops emphasising these aspects and this lead to a better understanding of EN by students. This argument may also be used to explain the relatively good understanding of TN. Since OI is related to EN and TN, it is understandable that the students also did reasonably well in this aspect of NOS.

The curricula do not address TL, SC and IC, which are complex concepts, and require an informed understanding that science is tentative and that science is influenced by other factors including technological innovations, societal, political and economic situations. Consequently, the poor performance of students in these aspects is not surprising.

In the case of SC, it is interesting to note that, despite the rich diversity of the South African cultural backgrounds, many students did not realise the relevance of social and cultural values in the generation of scientific knowledge. As mentioned previously, the NCAPS, unlike C2005 and RNCS, refocused on content and emphasised the importance of the current science knowledge, while dismissing the cultural and historical backgrounds that accompany the development of this knowledge. Students should be taught the history of developing knowledge as well as the difficulties experienced by scientists before arriving at the currently accepted science knowledge learnt in class. Clough (2011, p.56) states that, "moreover, the

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history and nature of science demonstrate scientists' conceptual struggles in trying to understand the natural world".

Students in the current study showed a poor understanding of imagination and creativity as well as the use of different scientific methods by scientists. A possible reason could be that in all the South African curricula, the "scientific method" is presented as the stating and testing of hypotheses. Students in schools are often taught to follow a scientific method comprised of a step-by-step procedure, starting with observing, writing down the problem statement, gathering data, formulating hypotheses to explain the data, planning, conducting investigations, interpreting data and drawing conclusions (e.g. Anderson, 2007; Bradley, 2005; Lunetta, Hofstein & Clough, 2007). Historically, the scientific method was proposed in the 1950s in Australia to encourage students to enrol for science courses in Australian universities (Bradley, 2005), and lead students to believe that this is the only way in which scientific knowledge is developed.

Ultimately, students need to understand that the nature of science involves a human interpretation of observations derived from natural phenomena. The learning of NOS involves the subjective interpretation of how different natural phenomena work. In other words, the subjective aspect of NOS is the umbrella word for all the aspects of NOS and it involves the subjective interpretation of the observations derived from natural phenomena.

The persistence of naïve beliefs about NOS may also be attributed to the type of teaching methods which emphasised finding the correct answer instead of developing knowledge. The traditional lecture approaches have not prepared students to be seekers of knowledge but rather to be recipients of knowledge (Friere, 1970). Consequently, many students hold the perception that scientific knowledge is the absolute truth and cannot change nor can it be influenced by social and cultural values nor is there any place for imagination and creativity.

In the transmission mode of teaching, students are encouraged to memorise content to succeed in the examination oriented curriculum (e.g. Blanchard, Annetta, & Southerland, 2008; Marzano, 1998; Yerrick, Parke, & Nugent, 1997). Moreover, due to the teaching and learning process, students developed certain beliefs about science knowledge, reflecting the same beliefs held by their teachers, that science knowledge is absolute and it is the only truth (e.g. Haney & McArthur, 2002; Lotter, 2004; Nespor, 1987). McDermott *et al.* (2000, p. 412) argued that "teachers tend to teach as they were taught. If they were taught through lecture, they are likely to lecture, even if such instruction is inappropriate for their students". Previous studies indicated that beliefs and attitudes influenced students' expectations about university science courses, how students' learn science, what they expect to learn and their perceptions of science careers (e.g. McDermott & Redish, 1999; Mistades, 2007; Sahin 2010; Stathopoulou & Vosniadou 2007).

McComas and Olson (1998) argue that school science should assist students to acquire appropriate conceptions of NOS and abilities to perform science. Put differently, students should be taught to understand how science works, how researchers work as a collective and how science advancements impact to society and environment. According to some researchers (Brown & Melear 2006; Lederman, 2007) many teachers also possess misconceptions about inquiry and how science works. However, teachers cannot be blamed for having developed certain beliefs since they are based on their previous experiences (Pajares, 1992; Richardson, 1996). Usually, when teachers are trained using either the

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teacher-centred or textbook-based approach, they are likely to teach the way they were taught (Akerson *et al.*, 2007).

Effect of ERGI laboratory practical activities on understanding of NOS

The experimental group showed the same trend as the control group discussed above, but performed better in each NOS aspect and, on average, performed 10 pp better than the control group across the NOS spectrum. These results suggest that, it is the combination of ERQs and GI activities that had an effect on student's understanding of NOS when compared to the combination of ERQs and traditional activities. Although the effect of 10 pp sounds rather modest, it is statistically significant at a 95% level of significance, and given the type of intervention, this is an insightful result.

In the individual NOS aspects, there was a noticeable effect in TN, IC and TL as well as a small effect in SC, SM, EN and OI. The reason for the differences in the effect is not clear.

The result, that both genders and high and low achieving students were affected, agrees with literature results that the understanding of NOS is not affected significantly by gender and academic achievement. It was established in the current study that different aspects of NOS showed different effects.

Effect of ERGI laboratory practical activities on academic performance

In as far as academic performance is concerned, the overall percentages show that, there were only very small differences observed between the experimental and control groups in their academic performance in the combined practical examination and theoretical year-end examination. Further analysis of some questions show large differences in the effect on high and low achieving students, showing that some ERGI laboratory practical activities were more successful for answering some questions. The reasons for the differences could be the subject of a future study and may give insight into the design of GI activities.

The small effect on overall academic achievement supports the evidence from literature which indicates that the intervention that follows Problem Based Learning is unlikely to find improvements in students' test scores (Albanese *et al.,* 1993; Vernon *et al.*, 1993).

However, there is evidence from literature that suggests that PBL increases the long-term retention of knowledge in comparison to traditional instruction (Gallagher, 1997; Martensen, Eriksson & Ingleman-Sundberg, 1985; Norman *et al.*, 1993). In addition, the development of critical thinking and problem-solving skills is enhanced when PBL is supplemented with explicit instruction addressing these skills (Di Vesta, & Smith, 1979; Wiggins & McTighe, 1998). Moreover, PBL is believed to promote individual independence and study habits among students as it enhances library usage, studying for understanding rather than simply relying on memory and attending class (Albanese *et al.*, 1993; Major & Palmer, 2001; Vernon *et al.*, 1993). Therefore, even though academic achievement was not improved, the value of GI activities was reflected in the better understanding of NOS. The expectation is that many of the outcomes above, although not tested, were affected.

As discussed earlier in Sections 1.3.1 and 2.1.4, the dichotomy between inquiry and traditional approaches is that inquiry in the current study allowed for a deeper level of understanding (improved understanding of NOS) in contrast to the traditional model that promotes surface learning (poor understanding of NOS) (Biggs 2003; Blakemore & Cousin, 2003; Brew & Boud, 1995; Magolda, 1999; McBride *et al.,* 2004; NRC, 2000; Prosser &

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Trigwell, 1999). However, the inquiry approach takes longer and is therefore less effective in teaching large volumes of work (Peek *et al.*, 1995). This might be the cause of the slightly worse performance of students in the experimental group in the combined practical examination. It was also observed that students performing the inquiry-based practical activities took longer to do the same experiment, consequently the practical activities were shortened to allow students to finish in the same time span.

Acceptance of ERGI laboratory practical activities by the students

From the start of the practical course, the students in the experimental group showed an acceptance of the ERGI laboratory practical activities. No students objected or asked to be dropped from the experiment. The experimental group students, who did the ERGI laboratory practical activities, felt that the practical course was not difficult and that the practical activities aided their understanding and gave them more confidence in applying physics. The use of guiding questions might have encouraged individual independence and assisted students in the discovery of science knowledge. Furthermore, they indicated that they enjoyed the more interactive nature of the experiments.

Interestingly, students in the control group said they appreciated the detailed recipe-like instructions, which suggests that these students still relied on the step-by-step procedure when conducting practical activities. Each group accepted the way they were taught: the control group did not feel that they were left behind, while the experimental group did not feel that they were test dummies.

5.6 Implications

The study clearly showed that there was a need for students to be educated on NOS. As described earlier in Section 2.1.1 of Chapter 2, the main objective of teaching NOS at all levels of education is to promote scientific literacy among citizens (e.g. Laugksch, 2000; Lederman *et al.*, 2012).

The effectiveness of GI combined with ERQs on NOS when compared to traditional approaches with ERQs has been demonstrated. This combination promoted the development of students' positive attitudes towards science learning and their understanding of NOS, in agreement with Apedoe (2008), Asay & Orgill (2010), and Schwartz *et al.* (2004) as discussed in Sections 1.9 and 2.3.9.

New knowledge and insights

The current study has to a certain extent been successful in equipping students with several skills. It has provided students with the learning environment that encouraged metacognitive, collaborative, argumentative and communicative skills. Students were able to create their own knowledge by establishing connections between their pre-existing knowledge and new experiences. Students were also engaged in cognitive processes used by scientists such as asking questions, formulating hypotheses, planning investigations, collecting and interpreting data, drawing conclusions and formulating theories. Students developed an understanding of science content and understanding the beliefs accompanying the development of science knowledge. It was interesting to note that although the students in the experimental group originally did not like the GI approach, they eventually saw the advantages and came to prefer this approach.

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Although GI practicals showed a positive effect on all aspects of NOS, there was not a positive effect on all aspects of the practical test. Therefore, there is a need to explore the factors that should be considered when planning and implementing ERGI laboratory practical activities. The design of the activities should match the students' different learning abilities in science. This may be coupled with the selection of activities of appropriate level of difficulty that will address students' misconceptions at different levels of understanding, to ensure success of inquiry-based practical activities.

5.7 Limitations of the study and suggestions for further investigations

The main objective of the current study was to examine the influence of the ERGI laboratory practical activities on first-year physics students' understanding of NOS, their attitudes towards laboratory work and their academic performance. Both qualitative and quantitative data were gathered and analysed with the intention of investigating this objective. Although there were some significant findings, the study had limitations. A significant limitation was the relatively small sample size used, which impeded the possibility of finding statistical significance for each NOS aspect.

Increasing the sample size may provide a researcher with an opportunity to find statistical differences in areas where the current study could not identify them. Using a larger sample size in terms of additional universities in South Africa and other countries may increase the ability of generalizing the results obtained from the sample to the larger population of first-year university students. The use of other universities would increase the possibility of discovering significant differences between measured variables.

A second limitation resulted from the fact that the current study was conducted in one country and one university, therefore, the results could not be generalised nor compared between different groups.

The third limitation was that, although the evaluation of NOS was done blindly by a researcher and co-researchers, the scoring of NOS responses remained subjective. It is therefore hard to compare studies by different authors when using the VNOS instrument.

The fourth limitation was that, due to the small sample size and ethical considerations, the study was not designed to allow determination of the effect of the ERQs per se. This could have been addressed with a larger sample with four groups instead of two could separate the effect of ERQs on NOS and GI.

In this study, no pre-test was given. This means that there is no information on the students' understanding of NOS before the start of the course. However, the aim of this study was to determine the effect of guided inquiry vs traditional practical activities, so as long as the initial groups were equal, any difference in the scores in the post-test may be ascribed to the different treatments of the two groups.

Equality of the two groups was assured by systematically assigning students to the control and experimental groups (Palinkas, Horwitz, Green, Wisdom, Duan, & Hoagwood, 2015), and the two groups can be assumed to be equivalent at the beginning of the study. The effect was measured by how experimental group performed in comparison with the control group. The effect of statistical fluctuations was dealt with by using of well-established statistical

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tests to determine the validity of the results. The lack of a pre-test, therefore, does not influence the validity of the comparative results.

As discussed in previous sections of this chapter, some of the findings in the current study confirm results in relevant literature, and some add new insights into the literature base. At the same time, the findings of the current study also reveal further research directions worthy of addressing in future studies.

For instance, two issues emerge because many students in the current study demonstrated a poor understanding of NOS aspects. This is a research and a practical issue. In terms of research, there is a need to examine the factors in learners' misconceptions of NOS, while at the practical level, there is a need to explore the factors that should be considered when planning and implementing ERGI laboratory practical activities. These factors should not be limited to encouraging all students to participate in the practical course, but the design of the intervention should address students' different learning abilities in science.

As a basis for further research, I suggest that the use of inquiry in both the theory in class and the practical laboratory experiments should be investigated.

5.8 Conclusion

5.8.1 Understanding of the Nature of Science

The control group showed a reasonably good understanding of EN, followed by TN and OI but a poor understanding of TL, SC, IC, and SM.

It was found that combination of GI laboratory practical activities and ERQs on NOS, used instead of traditional laboratory practical activities combined with ERQs, enhanced the students' understanding of all NOS aspects, and the overall NOS score showed a statistically significant effect on a 95% level of confidence with a *p*-value of 0.008.

Only an insignificantly small effect due to gender and academic achievement was observed.

5.8.2 Students' views on the laboratory work

Students in the experimental group expressed the view that they preferred the ERGI laboratory practical activities and felt it encouraged collaboration, equipped them with thinking and problem-solving skills, and assisted them to understand the relationship between scientific knowledge and real-life experiences.

5.8.3 Academic performance

When compared to traditional laboratory activities, the ERGI laboratory practical activities had only a very small effect on performance in the combined practical examination and the theoretical year-end examination. Although the average marks of the two groups in the combined practical examination were almost equal, it was found that high and low achieving students benefitted differently from some activities.

5.8.4 Reflection

The findings show that the students who participated in the course's ERGI laboratory practical activities enriched their views concerning all the NOS aspects. At the end of the

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practical course it was found that students in the experimental group generally displayed a better understanding in all aspects of NOS compared to the control group. The study was designed in such a way that both groups had the same ERQs to answer, and that the difference in the practical course lay in whether a traditional or inquiry-based approach was followed in the preceding laboratory practical activities. It therefore seems that the effect of the ERGI laboratory practical activities on students was to enhance their ability to engage with the work, and it enhanced the effect of the ERQs on NOS.

Despite the effect shown in NOS, there was only an insignificantly small effect as far as academic performance in both the combined practical examination and the theoretical year-end examination was concerned. However, further analysis showed that high and low achieving students benefitted differently from some activities.

Some conclusions that can be drawn from the current study include that no single approach employed in teaching of NOS will solve all the problems involved in the better understanding of science knowledge. This implies that the inquiry approach will not solve all the teaching and learning problems. Some of the educational research studies in respect of one approach seem to be useful in clarifying teaching and learning problems. However, the use of only one approach, without supplementing it by other teaching approaches, might not lead to a better understanding, whether the test subjects are males or females, or high or low achievers, for all science. The use of different teaching approaches should be guided by the contextual factors including students' background, students' prior knowledge, learning environment and available teaching resources. Sometimes the use of either traditional or inquiry approaches and sometimes the combination of these two may help in making students understand science better. Put differently, either the traditional or inquiry approaches could be used depending on what the teaching and learning situations in a classroom situation demand.

The present study aimed to contribute to the body of science knowledge by investigating students' learning experiences under ERGI laboratory practical activities. It is the researcher's hope that the findings of the current study may contribute to the literature on inquiry-based instruction and offer a guideline for further study. Specifically, the success of combining GI with an explicit–reflective NOS instruction model could support the use of new approaches in teaching NOS.

5.9 Recommendations

This study attests to the usefulness and importance of the combination of GI and ER in understanding NOS. Although GI and ER did not have an effect in the learning of science content, it is recommended that science teachers should be equipped with knowledge regarding, "How should science be taught?" and "How should NOS be taught?" Each of the two recommendations was discussed below.

5.9.1 How should science be taught?

Science learning is viewed as a process of developing an understanding of domain-specific knowledge embedded in human cognition and cognitive development (Brown, 1990; Carey & Spelke, 1994; Gelman & Brenneman, 2004). Domain-specific assumptions agree with classic developmental theories that individuals should be actively involved in the construction of knowledge (Bruner, 1996; Piaget, 1955; Vygotsky, 1962). Domain-specific approaches indicate that learning in science and mathematics is illustrated by the development of diverse

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theoretical structures and methods. The use of the domain-specific perception in science teaching could help students develop an understanding of central ideas and to acquire thinking skills fundamental to the learning of science. In addition, science learning is viewed as a social process embedded in certain cultural settings (Boyd & Richerson, 2005; Driver *et al.,* 1994). These perspectives agree with the research in science education, which assumes that science knowledge and science practices are embedded in and influenced by certain socio-historic situations (Kuhn, 1977; Laudan, 1990; Thagard, 2004).

The effective teaching of physics should involve using approaches that encourage constructivist learning, the conceptual understanding of physics topics and the development of skills which encourage students to understand the aspects of NOS and the processes of scientific inquiry (e.g. Darling-Hammond, 2000; Marzano, 2007; Schwartz, Lederman & Lederman, 2008). During science instruction, students should be asked leading questions, and be guided and supported in their discovery of knowledge (e.g. Bransford *et al.,* 1999; Zion & Slezak, 2005).

However, the implementation of the above stated principles is not without difficulties. Reif (2008) argued that students are likely to develop negative attitudes towards inquiry if they are not fully prepared to deal with the challenges of inquiry learning. For instance, students who score well in conventional methods are likely to object to the inquiry-based instruction as they feel threatened and exposed if they have to present their ideas in front of the whole class. When students are not exposed to new teaching approaches that encourage them to build on their cognitive dissonance, they become frustrated because they lack the necessary mental tools to alleviate this dissonance (Kirschner *et al.,* 2006; Zion *et al.,* 2007).

Felder *et al.* (1996) suggested that climate setting is a preventative measure that could minimise students' resistance to inquiry-based instruction. Students should be taught of the effectiveness of student-centred learning from the outset. Schulz and Mandzuk (2005) recommend that the responsibilities of a teacher should change from a disseminator of information to be memorised by students to a facilitator of learning. When students encounter cognitive dissonance the facilitator's responsibility is to advise students that even the best students require time to develop a full understanding (Reif, 2008).

5.9.2 How should NOS be taught?

There seems to be extreme differences in science education research about the degree to which NOS should be taught. On the one hand, several researchers have shown that students may demonstrate better understanding of different features of NOS when engaged in investigative activities (e.g. Schwartz *et al.,* 2004). Other researchers have argued that students may demonstrate an informed understanding of NOS if they are explicitly taught (e.g. Lederman, 2007). A third group of researchers suggested that the integration of explicit approach and inquiry might promote a better understanding of NOS aspects (e.g. Clough & Olson, 2008). These scholars have argued that the use of high level intellectual guiding questions combined with inquiry may assist students to develop a better understanding of NOS aspects. The latter view is a view that was investigated by the current study.

The ERGI laboratory practical activities used in the present study provided inquiry opportunities that allowed students to experience how scientific claims were developed by researchers and were justified rather than the passive reception of ready-made answers

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(Sandoval, 2005). In the ERGI laboratory practical activities, students were taught by being guided through intellectually guiding questions that encouraged development of thinking skills, with the objective of preparing students to become independent problem solvers. This explicit approach also prepared students to always reflect on any undertaking when performing laboratory practical activities. When students were engaged in solving problems and reflecting on laboratory practical activities, they made remarkable gains in understanding how science knowledge was developed, as well as acquiring skills in simple scientific practices (Costa & Kallick, 2000).

The results obtained from the VNOS questionnaire and interviews in the present study may be more universal, as they agree with Ibanez-Orcajo & Mart´ınez-Aznar (2007) as well as Ryder, Leach and Driver (1999). The NOS results in the current study concur with Zeidler, Walker, Ackett, and Simmons (2002, p.361) who indicated that,

> "Instead of the NOS being taught as a discrete topic in the delivery of a course, this study suggests that it may be successfully integrated into the curriculum being taught when students are actually experiencing those aspects of the NOS while involving in scientific inquiry and addressing anomalous data."

It was therefore concluded that the ERGI laboratory practical activities had enhanced students' understanding of NOS and physics concepts when compared to traditional practical activities. Additionally, the ERGI laboratory practical activities had a minimal effect on the academically high and low achieving students' performance in the physics course. This further implies that, to increase the performance of the high and low achieving students in the learning of physics and NOS, a mixed approach that integrates GI and traditional teaching strategies should be used.

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Appendices

Appendix A: An invitation letter and consent form to participants

Appendix B: Application letter of permission and consent form to the Dean of the Faculty of Education

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Appendix A: Letter of permission to students

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA
Fakulteit Natuur- en Landbouwetenskappe

Dear BSc (Physics) student,

Participation in the study: Influence of guided inquiry-based laboratory activities on outcomes achieved in a first-year physics course.

As a first-year Bachelor of Science student, you are cordially invited to participate in a study of the Physics Department of the University of Pretoria. The aim of the study is to investigate the influence of different approaches to laboratory activities.

The PHY 114 course has a compulsory practical component, in which all students have to participate. This component contributes 10% to your final mark. We would like to invite you to participate in a study in which we want to determine the influence that the approach taken in the practical has on your learning. If you give permission to partake in this study by signing this consent form you will be randomly allocated to do one of two different sets of practicals. Both practicals have similar content, use similar equipment and have equal contact time, only the approach differs. Should you prefer not to participate in the study, you will be included in the group of following the traditional approach, but your practical results will not be included in the data collected for this study. Should you prefer, you may at any time withdraw your consent, and move to the traditional group.

At the end of the semester, we will ask you to complete a voluntary questionnaire with the aim of determining what you have learnt during the practicals. The results of this questionnaire will only be processed AFTER the final results of the course are published, so your results in this questionnaire will not have ANY influence on your academic marks.

We also request permission that the researcher may be given your practical workbook, practical tests and the marks obtained in these tests as well as your final mark. Again, participating in this study will not have ANY effect on your final mark, as the processing of these results will only be done after your final marks have been published by the University.

Although aggregate results of the study will be published, no individual will be identified at any stage of the research, and your answers in the questionnaire will not have an influence on your academic marks for the course.

The research methodology has been approved by the Ethics Committees of the Faculty of Education and Faculty of Natural and Agricultural Sciences and the results will be treated according to the ethics regulations of the University of Pretoria.

We would appreciate it very much if you could take part in the above mentioned study. The successful completion of this study will help us gauge the influence of the approach taken in practials on the success of students.

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Please note that participation in this study is voluntary, and that you may at any stage withdraw from the study. All students have to do practicals but the results of students that do not give their consent, will be excluded from the study.

Should you have any further questions, please feel free to contact any of the investigators listed below.

Kind Regards

Mr Vonani Baloyi (MEd) (PhD student)
Vonani.baloyi@up.ac.za, tel: 012 420 4967

Signature

Prof Walter Meyer (PhD) (Supervisor)
Walter.meyer@up.ac.za, tel: 012 420 2637

Signature

Dr E Gaigher (Co-supervisor)

Prof MHW Braun (Co-supervisor)

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UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA
Fakulteit Natuur- en Landbouwetenskappe

Consent form to participate in the study "Investigating the influence of guided inquiry-based laboratory activities on outcomes achieved in a first-year physics course".

1. Research study

I, ____, (full name) student number

____________, agree to take part in the study "Investigating the influence of guided inquiry-based laboratory activities on the achievement of outcomes in a first-year physics course". The study is part of the research done by the Physics Department of the University of Pretoria.

2. Purpose of the Study

The aim of the study is to explore whether changing the approach taken during practical sessions influence first-year physics students' learning.

3. Description of Procedures

The PHY 114 course has a compulsory practical component. Students giving their permission by signing the consent form will be randomly selected to do one of two different sets of practicals. Both practicals have similar content, use similar equipment and have equal contact time, only the approach differs. Students that do not consent will be assigned to the "traditional" practical group, and their results will not be taken into account in the study.

At the end of the semester, we will ask you to complete a voluntary questionnaire with the aim of determining what you have learnt during the practicals. The results of this questionnaire will only be processed AFTER the final results of the course are published, so your results in this questionnaire will not have ANY influence on your academic marks.

Students will also be invited to participate in voluntary focus-group interviews in which you will be given an opportunity to share how you experienced the practicals. A researcher will conduct observations of laboratory activities.

In this study, the researcher requests that he may make use of the following information in his study:

- Your completed practical worksheets and practical test papers
- Marks obtained in the practical test
- Final grade in the physics course
- Grade 12 results
- Biographical information: Home language and the name of the school you attended

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4. Voluntary participation
Participation in this evaluation is voluntary and may be withdrawn at any time.

5. Confidentiality
All information will be treated strictly confidential. At no time will your name or any information that may identify you personally be made public.

Although aggregate results of the study will be published, no individual will be identified. No information by which you can be identified will be released or published. Your answers will not be revealed to your lecturer and will not have any influence on your marks.

I have read all of the above, had the opportunity to ask questions, received answers concerning areas I did not understand and I willingly give my consent to participate in this study.

I have received a copy of this form, which I will keep for my reference.

Name: ____

Signature: _________________________________ Date: ________________

If under the age of 18 years on date of signing, we also require the signature of your parent or guardian

Name: ____

Signature: _________________________ Date:________________

Witness 1: _________________________ Date: ________________

Witness 2: _________________________ Date: ________________

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Appendix B: Application letter of permission and consent form to the Dean of the Faculty of Education

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA
Fakulteit Natuur- en Landbouwetenskappe

19 June 2014

Prof I Eloff
Dean: Faculty of Education
University of Pretoria

Dear Prof Eloff

Request to conduct research with UP students for the PhD research study "Investigating the influence of guided inquiry-based laboratory activities on outcomes achieved in a first-year physics course" by Mr VM Baloyi.

Mr Vonani Michael Baloyi is currently in the third year of his PhD studies in the department of Science, Mathematics and Technology Education in the Faculty of Education of the University of Pretoria, under the supervision of myself, Prof W.E. Meyer (Department of Physics), and Dr E Gaigher (Department of Science, Mathematics and Technology Education). His studies and subsistence are financed by a SASOL Inzalo bursary, which covers three years. He has successfully defended his research proposal for his PhD during 2013. His PhD envisaged involving students from the University of Pretoria, in the Department of Physics. The project, including the collaboration with the University of Pretoria was decided upon from the start of his studies, in consultation with the head of the Department of Science, Mathematics and Technology Education, at which stage there was no indication that the University of Pretoria would object to UP students being part of the investigation. In fact, a number of similar studies were underway. The main reason for me accepting Mr Baloyi as student was that he had an interest in physics practicals, and the project would overlap with my own interest in physics teaching.

Only at the end of 2013, when we applied for ethics approval, were we informed that permission to use UP students as subjects would not be given. As a result, the plans made and materials developed over a number of months could not be used. As a second (and probably last) opportunity, we hope to perform the experiment during the second semester of 2014 with a group of approximately two hundred physics (PHY 124) students. This will allow Mr Baloyi to complete his PhD, albeit 6 months later than planned. This delay would have financial implications for the student, which we will have to mitigate. I also enclose a letter by the head of the Physics department confirming the Department's support for this project.

The research question investigated by Mr Baloyi is:

"*To what extent does explicitly reflective guided inquiry-based instruction in practical laboratory activities influence the outcomes achieved in a first-year Physics course?"* with the sub question:

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1. *To what extent do guided inquiry-based laboratory activities promote:*

- *understanding of the nature of science,*
- *scientific reasoning abilities,*
- *attitudes towards science learning,*
- *understanding of scientific inquiry,*
- *conceptual development,*
- *academic performance?*

In short, the proposed project uses the opportunity provided by the Department of Physics that is currently in the process of redesigning the laboratory section of a physics course to convert it from a traditional approach to an inquiry-based format. This offers us an opportunity to explore the effect that guided inquiry has on the outcomes achieved in a first-year Bachelor of Science physics course. Science education research studies show that inquiry-based laboratory activities promote students' thinking skills more effectively than the traditional recipe-based approach. Due to the uniqueness of this opportunity, it is unlikely that a similar opportunity will arise at another University.

The adoption of the guided inquiry approach is an application flowing from the international cooperation on inquiry based science education between Dr Gaigher from UP and Prof NG Lederman and JS Lederman at Illinois Institute of Technology in Chicago. Inquiry based science teaching is currently considered the best practice approach to science teaching. The University of the Free State, Nelson Mandela Metropolitan University and the North West University have shown interest in our studies, and might, depending on our experience, consider a similar switch in future. We hope to compare outcomes with possible future experiences at these universities.

The results from this study will be used to determine the effect of guided inquiry-based laboratory activities on outcomes achieved by first-year Physics students. These results will gauge the effect of modern teaching techniques on students' attitudes and performance and thereby contribute to excellence in teaching and learning at UP. In addition, is hoped that this new approach may provide a method to address the different challenges experienced by physics students coming from different backgrounds in the South African context. A journal article for submission to an ISI-indexed journal will be prepared. In addition, some of the results from this study will be published in the African Journal of Research in Mathematics Science and Technology Education and presented at the South African Institute of Physics conference, and submitted for publication in the proceedings.

As is the preferred practice, the study leader (Prof Meyer) is not the lecturer for the course in which we are adopting guided inquiry based practicals, and additional testing for this project will be done during lectures. We will, however, make use of data collected in class as part of standard conceptual tests that are given by the lecturer to evaluate student's prior knowledge and learning.

As requested, the identity of the institution at which the students are studying will not be mentioned in any publication without prior written approval.

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We hereby request permission to run the experiment during the second semester of 2014 with a group of approximately two hundred PHY 114 students.

We will be grateful if our request could receive your consideration and you could forward it to the appropriate authorities. If you have any questions, do not hesitate to contact any of the undersigned at the telephone numbers given below, or via e-mail.

Enclosed the completed prescribed ethical clearance questionnaire as well as a letter of support from the head of the Physics Department, Prof Chris Theron.

Yours faithfully

Signature

Walter E Meyer
(Associate Professor: Department of Physics)

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Appendix C: Letter of permission: Department of Physics

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA
Faculty of Education

19 June 2014

Prof CC Theron
Head: Department of Physics
University of Pretoria

Department of Science, Mathematics and Technology Education
Tel: +27 (0)12 420 5659 Fax: +27 (0)12 420 5621

Dear Prof Theron

Request for permission to conducting research in the Department of Physics at the Faculty of Natural and Agricultural Sciences

I am Vonani Michael Baloyi a PhD student at the Faculty of Education of the University of Pretoria, under the supervision of Prof WE Meyer, Prof MHW Braun and Dr E Gaigher. I hereby request your permission to conduct research in the Department of Physics.

The topic is entitled: **Influence of guided inquiry-based laboratory activities on outcomes achieved in a first-year physics course.** The aim of the research project is to explore whether changing some of the traditional laboratory activities into guided inquiry format followed by reflective questions aimed at inquiry-based discovery of specific aspects of NOS may influence first-year physics students' outcomes. These outcomes include, scientific reasoning skills, conceptual development of scientific knowledge, understanding of scientific inquiry, and academic performance, and attitudes towards science learning and students' views on the nature of science.

Students will be requested to volunteer to take part in the study and are free to refuse to participate and to withdraw from the study at any time. The experimental procedure would involve dividing the participants into two groups, one of which will perform practicals based on the guided inquiry based approach, while the other will perform practical according to the traditional recipe based approach. (Students not participating in the study will follow the traditional practicals, and their results will not be taken into account during the study.)

Redesigning the laboratory of a physics course from a traditional approach to an inquiry-based format offers an opportunity to explore the effect that guided inquiry has on the outcomes achieved in a first-year Bachelor of Science physics course. Literature reports indicate that inquiry-based laboratory activities promote students' thinking skills more effectively than the traditional recipe-based approach.

The results from this study will be used to determine the effect of guided inquiry-based laboratory activities on outcomes achieved by first-year Physics students. This may lead to recommendations for future research and may contribute to improvement of science teaching.

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If you grant me permission to do the research at your department, I shall administer four questionnaires with the students and conduct focus group interviews with randomly selected students from both control and experimental groups (one questionnaire per student). I will also conduct focus group interviews, which will be videotaped, transcribed and analysed. In addition, I will observe the practical sessions using an observation checklist which will monitor students approach to solve problems, the interactions amongst students and interactions between students and laboratory assistants. Students' practical worksheets, practical test marks and their Physics course examination marks will be needed for analysis and comparing students' performance between control and experimental groups. This process will not affect the normal lectures, as these interviews and discussions will be done outside of the normal lecture sessions. I attach a copy of the research proposal for your information.

Students should be at least eighteen years old to participate in this study. Identities of students and the university will be held strictly confidential and only aggregate results will be published. To further anonymity, student numbers will be used during data collection and analysis.

The information that is collected will be used for academic purposes only. In my research report and in any other academic communication, the university will not be identified without permission and no other identifying information will be given.

If you agree to allow me to conduct this research in your department, please fill in the attached consent form. If you have any questions, do not hesitate to contact my supervisor or me at the numbers given below, or via E-mail.

Yours faithfully

Signature	Signature
VONANI MICHAEL BALOYI (MR)	**PROF WE MEYER**
Researcher	Supervisor, Department of Physics

Researcher details:	**Supervisor:**	**Co-supervisor:**
Mr Vonani Michael Baloyi	Prof WE Meyer	Dr E Gaigher
Tel: 012 420 4967	Tel: 012 420 2637	Tel: 012 420 5663
Cell: 0724222691	Cell: 0827858432	E-mail:estelle.gaigher@up.ac.za
E-mail: vonani.baloyi@up.ac.za	E-mail: walter.meyer@up.ac.za	

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CONSENT FORM

I, _______________________________________, Head of the Department of Physics …agree / do not agree (delete what is not applicable) to allow the research project titled: **Influence of guided inquiry-based laboratory activities on outcomes achieved in a first-year physics course** to be performed in this Department of Physics in the Faculty of Natural and Agricultural Sciences of the University of Pretoria. I understand that the practical sessions of participating students will be observed and that three or four groups of randomly selected students from both control and experimental groups will be interviewed about this topic for approximately 30 to 60 minutes at a venue and time that will suit them. The interview will be recorded.

Some written practical worksheets, practical test marks and Physics course final examination marks of students will be reviewed, but only if students have given permission for their activities to be used as data in this study. Observations of all the practical sessions will be conducted using an observation checklist which will focus on how students attempt to solve a given problem, interactions amongst students and interactions between students and laboratory assistants.

I understand that the researchers subscribe to the principles of:

- *voluntary* participation in research, implying that the participants might withdraw from the research at any time.
- *informed consent*, meaning that research participants must at all times be fully informed about the research process and purposes, and must give consent to their participation in the research.
- *safety in participation*, put differently, that the human respondents should not be placed at risk or harm of any kind e.g. research with young children.
- *privacy*, meaning that the *confidentiality and anonymity* of human respondents should be protected at all times.
- *trust*, which implies that human respondents will not be respondent to any acts of deception or betrayal in the research process or its published outcomes.

The study will only proceed once ethical clearance has been obtained.

Signature:__________________________ Date:___________________

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Appendix D: Letter of permission: Faculty of Natural and Agricultural Sciences

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA
Faculty of Education

Department of Science, Mathematics and Technology Education
Tel: +27 (0)12 420 5659 Fax: +27 (0)12 420 5621

19 June 2014

Prof M Potgieter
Dean: Faculty of Natural and Agricultural Sciences
University of Pretoria

Dear Prof Marietjie

Request for permission to conducting research in the Department of Physics at the Faculty of Natural and Agricultural Sciences

I am Vonani Michael Baloyi a PhD student at the Faculty of Education of the University of Pretoria, under the supervision of Prof WE Meyer, Prof MHW Braun and Dr E Gaigher. I hereby request your permission to conduct research in the Department of Physics within the Faculty of Natural and Agricultural Sciences.

The topic is entitled: **Influence of guided inquiry-based laboratory activities on outcomes achieved in a first-year physics course.** The aim of the research project is to explore whether changing some of the traditional laboratory activities into guided inquiry format followed by reflective questions aimed at inquiry-based discovery of specific aspects of NOS may influence first-year physics students' outcomes. These outcomes include, scientific reasoning skills, conceptual development of scientific knowledge, understanding of scientific inquiry, and academic performance, and attitudes towards science learning and students' views on the nature of science.

Students will be requested to volunteer to take part in the study and are free to refuse to participate and to withdraw from the study at any time. The experimental procedure would involve dividing the participants into two groups, one of which will perform practicals based on the guided inquiry based approach, while the other will perform practical according to the traditional recipe based approach. (Students not participating in the study will follow the traditional practicals, and their results will not be taken into account during the study.)

Redesigning the laboratory of a physics course from a traditional approach to an inquiry-based format offers an opportunity to explore the effect that guided inquiry has on the outcomes achieved in a first-year Bachelor of Science physics course. Literature reports indicate that inquiry-based laboratory activities promote students' thinking skills more effectively than the traditional recipe-based approach.

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The results from this study will be used to determine the effect of guided inquiry-based laboratory activities on outcomes achieved by first-year Physics students. This may lead to recommendations for future research and may contribute to improvement of science teaching.

If you grant me permission to do the research at your department, I shall administer four questionnaires with the students and conduct focus group interviews with randomly selected students from both control and experimental groups (one questionnaire per student). I will also conduct focus group interviews, which will be videotaped, transcribed and analysed. In addition, I will observe the practical sessions using an observation checklist which will monitor students approach to solve problems, the interactions amongst students and interactions between students and laboratory assistants. Students' practical worksheets, practical test marks and their Physics course examination marks will be needed for analysis and comparing students' performance between control and experimental groups. This process will not affect the normal lectures, as these interviews and discussions will be done outside of the normal lecture sessions. I attach a copy of the research proposal for your information.

Students should be at least eighteen years old to participate in this study. Identities of students and the university will be held strictly confidential and only aggregate results will be published. To further anonymity, student numbers will be used during data collection and analysis.

The information that is collected will be used for academic purposes only. In my research report and in any other academic communication, the university will not be identified without permission and no other identifying information will be given.

If you agree to allow me to conduct this research in your department, please fill in the attached consent form. If you have any questions, do not hesitate to contact my supervisor or me at the numbers given below, or via E-mail.

Yours faithfully

VONANI MICHAEL BALOYI (MR)
Researcher

PROF WE MEYER
Supervisor, Department of Physics

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CONSENT FORM

I, ______________________________________, Dean of Faculty of Natural and Agricultural Sciences …agree / do not agree (delete what is not applicable) to allow the research project titled: **Influence of guided inquiry-based laboratory activities on outcomes achieved in a first-year physics course** to be performed in this Department of Physics in the Faculty of Natural and Agricultural Sciences of the University of Pretoria. I understand that the practical sessions of participating students will be observed and that three or four groups of randomly selected students from both control and experimental groups will be interviewed about this topic for approximately 30 to 60 minutes at a venue and time that will suit them. The interview will be recorded.

Some written practical worksheets, practical test marks and Physics course final examination marks of students will be reviewed, but only if students have given permission for their activities to be used as data in this study. Observations of all the practical sessions will be conducted using an observation checklist which will focus on how students attempt to solve a given problem, interactions amongst students and interactions between students and laboratory assistants.

I understand that the researchers subscribe to the principles of:

- *voluntary* participation in research, implying that the participants might withdraw from the research at any time.
- *informed consent*, meaning that research participants must at all times be fully informed about the research process and purposes, and must give consent to their participation in the research.
- *safety in participation*, put differently, that the human respondents should not be placed at risk or harm of any kind e.g. research with young children.
- *privacy*, meaning that the *confidentiality and anonymity* of human respondents should be protected at all times.
- *trust*, which implies that human respondents will not be respondent to any acts of deception or betrayal in the research process or its published outcomes.

The study will only proceed once ethical clearance has been obtained.

Signature:_________________________ Date:__________________

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Appendix E: An observation checklist

An observation checklist was guided by the work of Hofstein and Lunetta (1982).

An observation checklist for the laboratory practical sessions

Date____________ **Time**____________ **Experiment**____________________

Group__________ **Technical assistant**____________________________

Oberserver ____________________________

Scale used: 1=Never, 2=Rarely, 3=Most of the time and 4=always

Observation check list		**Score**	**Comments**
A. **laboratory setting**	Clean		
	Attractive		
	Availability of equipment		
	Safe		
B. **Are students' interactions within groups**	Arrive to the laboratory on time		
	bring necessary materials		
	Follow laboratory guide		
	Listen to laboratory assistants		
	Reflect on what they are doing		
	Discussion between members of a group		
	Discussion between different groups		
	Discussion (vs. collecting of information) amongst peers		
	Are these discussions conducive to learning?		
	Availability of assistant		
	Students have sufficient access to assistant		
	Respect others' opinions		
	Skill level (observation skills, inquiry and problem-solving skills, mathematical skills, reading skills, and manipulative skills)		
	Interest and curiosity		
	Conceptual understanding		
	Intellectual development		
C. Laboratory assistants' interactions with students	Demonstrates productive character traits (i.e. patience, thorough, hardworking)		
	Demonstrates a level of concern for students		

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	Encourages students to remain on task		
	Laboratory assistants' move between students		
	Gives clear directions / guidance to students		
	Assistant guides students to the right answer through questioning		
	Assistant gives the correct answer immediately / shows students immediately		
	Appropriate time management		

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Appendix F: Views of Nature of Science Questionnaire VNOS – Form C

Views of Nature of Science Questionnaire VNOS – Form C

1. 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)?
2. What is an experiment?
3. Does the development of scientific knowledge require experiments? If yes explain why. Give an example to defend your position. If no explain why. Give an example to defend your position.
4. 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. Defend 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? Defend your answer with examples.
5. Is there a difference between a scientific theory and a scientific law? Illustrate your answer with an example.
6. 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?
7. Science textbooks often define a species as a group of organisms that share similar characteristics and can interbreed with one another to produce a fertile offspring. How certain are scientists about their characterisation of what a species is? What specific evidence do you think scientists used to determine what a species is?
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?
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 practiced. 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.
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

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collection? Please explain why scientists use imagination and creativity. Provide examples if appropriate.

- If you believe that scientists do not use their imagination and creativity, please explain why. Provide examples if appropriate.

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Appendix G: Explicit-reflective NOS questions used during the practical course

1. (SHM experiment) Data was collected from the Simple Harmonic Motion experiment and later analysed. Conclusions were drawn from the data. Do you believe that scientists use imagination and creativity when analysing and drawing conclusions from the data like you did in this practical? Answer yes or no and explain your answer.
2. (EKS experiment) In the Exponential Decay experiment, we say that the data followed an exponential decay law. The law can be explained by a statistical theory. Other examples of laws are the ideal gas law, which is explained by the kinetic-molecular theory. Explain how scientific laws and theories are different types of knowledge, yet they relate to one another. Can you give another example of a law and a theory to make the distinction clear?
3. (CIR experiment) Ohm based his law, ohm's law $R = V/I$ on accurate measurement and precise calculations. However, in his time he experienced enormous resistance from many people (including leading scientists of the time) because there was a belief that physical world is highly ordered and can be accurately explain by reasoning and not by experiments. Taking this into account, what do you think is the main reason for conducting experiments?
4. (RC experiment)Early theories held that electricity was a liquid that could be stored in a bottle, lined on the inside and outside with metal, called a Leyden Jar. Now we know that the Leyden Jar was actually a capacitor in which charge could be stored. Is it possible that our current theory of electricity might be replaced by a new theory? If yes, what would have to happen to cause such a change?
5. (OSS experiment) Through the ages, science was studied by many different civilizations that had different cultures. For instance, in 700 BC, the ancient Babylonians developed a sophisticated system to predict the positions of planets. However, the motion of these planets was seen as something mystical, associated with astrology and divination. Do you think that scientific knowledge is influenced by the social and cultural values of the environment where it was developed?
6. (AC experiment) In this experiment, you were guided by the practical notes. Do you think that all scientists use one scientific method when developing scientific knowledge?
7. (TRA experiment) In the early years of electricity generation, there was an argument between the supporters of Edison, who believed DC should be used for electricity distribution and the supporters of Tesla, who believed AC should be used. In the end, calculations showed that an AC distribution system using transformers was far more efficient than a DC distribution network, and AC became the dominant technology. Taking this history into account, how do conclusions reached in science differ from conclusions reached in other disciplines such as philosophy and art?

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Appendix H: Focus group interview questions

1. How did you experience the practical activities in general?
2. Would you prefer more guidance in the practical activity or more opportunity to investigate in your own way?
3. Which practical activity did you enjoy most and why?
4. Which practical activity did you enjoy least and why? What in your view is science?
5. What makes science (or a scientific discipline such as Physics, Chemistry, etc.) different from other disciplines of inquiry (e.g. art and philosophy)? Do you think the practical activities influenced your views in this regard?
6. 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 appropriate. Do you think the practical activities influenced your views in this regard?

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Appendix I: VNOS evaluation matrix

Targeted aspect of NOS	**VNOS Form-C question**	**Informed view** (Answers clear and unambiguous.)	**Mixed view** (If something would have been informed ideas but answers contain contradictions or ambiguity).	**Naïve view** (Answers suggest that science is absolute truth, reference to proving facts)
Empirical nature	1.	Science knowledge differs from other disciplines like art and philosophy because it is focused on *natural phenomena*. Science is based *on empirical evidence (or both* observation of natural phenomena and experiments.	Refers to natural phenomena, proof or evidence and does not explicitly include or exclude observations of natural phenomena.	Science knowledge is generated using *experiments only/scientific method*. No indication that science studies the natural world.
	2.	An experiment is a planned procedure carried out in a *controlled environment* (test) where there is a *manipulation of variables and control of variables/ testing/ measurement of results/ observations made/ making conclusions*. It seeks evidence supporting or discrediting a theory or hypothesis, but may not prove it correct.	To test/confirm whether a suggested hypothesis/ claim/ idea is correct or not.	To prove whether a law or a theory is correct. A sequence of steps, following the scientific method. Collecting data. Procedure to find the truth. To be sure of facts.
	3.	Science is based on *empirical evidence/ observations and experiments, with suitable examples*. *A well-argued no, not only experiments, but also observation and human input (e.g. theory of evolution did not involve experiments)* *Yes, (e.g. Newton's 2nd law is based on experimental evidence) but also observations and human input.*	To test whether a suggested hypothesis/ claim/ idea is correct or not. Yes, empirical evidence is required (but no reference that observations and human input is also required) **Examples:** Science experiments are conducted to generate evidence that *supports scientific claims* e.g. Ohm's law.	To prove whether a law or theory/ a fact is correct/true. Yes/No, without explanation
Tentative nature	4.	Scientific knowledge is *tentative* (subject to change). New knowledge is being discovered from time to time because *of advancement in technology*, thus old scientific *theories are continuously modified and changed*. Theories may also change when a scientist thinks differently about existing knowledge and develops a new theory that may be	Science knowledge may change. Argument not clear, no appropriate examples given	Scientific theories and laws do not change because they were proven to be correct many years ago. Theories may change into laws over a certain period of time.

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		accepted by others. ***NB** (A well-argued **yes** gets a 3 but a well-argued **no** gets a 2)* *E.g. Atomic theory has developed over centuries* *b) We bother to learn theories as they represent current knowledge.*		
A difference between a scientific theory and a scientific law.	5.	Scientific theories *are broad/general explanations of natural phenomena using constructs that are not directly observable.* Scientific laws *are specific descriptions of relationships /patterns between phenomena which are directly observable in an experiment /investigation. E.g. the particle theory of matter versus the universal gas law.* Scientific theories and laws are both *scientific knowledge and all of them are tentative*. ***NB** (A well-argued **yes** gets a 3 but a well-argued **no** gets a 2).*	Scientific theories *do not change* or *are not completely changed but modified*. Scientific theory may not be proven (*not believed to be true*) but scientific laws (*believed to be true*) can be proven in an experiment.	Scientific theories and laws *do not change*. Scientific theories *will change into laws with time*.
Role of imagination and creativity/ tentative nature	6.	They may not be sure, they just *develop a theory that explains the data* and that may be understood by human minds. They use evidence based on data to support their theory/model in order to explain the data. Scientists *use their imagination and creativity* in the development of scientific knowledge. This creation of scientific knowledge is based on *observations and inferences of the natural world*. Many conclusions may be drawn from the *empirical evidence* through the use of imagination and creativity. *Scientists create models of natural phenomena in science but these scientific models are not copies of reality*. ***NB** (A well-argued **No** gets a 3 but a well-argued **Yes** gets a 2).*	Scientists use creativity but not imagination or vice versa when conducting scientific investigations.	They are sure because they observed it/ did experiments/ it is a fact. Scientists do not use imagination and creativity but they draw conclusions from the collected data. Scientists base their results on the experimental evidence.

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Subjective nature of scientific knowledge/ Difference between human observations & inferences	7.	Scientific knowledge is not always certain, e.g. the historical classification of wolves and dogs as separate species contradicts the definition of species. The concept of species is a human, creative construct. Historically, scientists used observable differences and cultural ideas in classifying species. Scientists from different fields of science are guided by their *different prior experiences, social and cultural values and research expertise when investigating and making conclusions.* *At least more than two different methods should be mentioned.* Science is based on both observation and inference. Observations are gathered through human sense organs or extensions of human senses. Inferences are interpretations of the observations.	They were sure about classification but that changed when new information becomes available. They used visible differences to classify species	The classification was a mistake. Scientific knowledge is certain and universal. Species are classified by obvious differences
Subjective nature of scientific knowledge (theory-laden)	8.	Science is a *human endeavour*. Scientists may share some critical assumptions including the gathering of data, the importance of logical reasoning, and the need to derive their explanations from evidence. However *scientists differ in their experiences, perceptions, research expertise, imagination, creativity and courage*. Given the same empirical evidence, *individual or group of scientists may come up with different explanations.* *All base their explanations on empirical evidence, but all are guided by different social and cultural values and by imagination and creativity*. All have to interpret data, to gather evidence that supports the explanation they prefer to accept.	Both groups may be right. They may not be sure because there is not enough data. Science knowledge was *once influenced* by religious and philosophical beliefs but that has changed with time.	One group interpreted the data incorrectly, they made a mistake. Science knowledge is *not influenced by social and cultural values* as it is based on experimental evidence.
Influence of social and cultural	9.	Science knowledge is social and culturally embedded. This implies that scientific	Science knowledge was once influenced by religious and	Science knowledge is not influenced by social and cultural

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factors in the generation of scientific knowledge.		knowledge is *always influenced by contextual factors (such as the political, economic, social and cultural values)* of the context in which it was developed. The *experiences, social and cultural beliefs and expertise of scientists in different fields of science* also play a role in the development of scientific knowledge. E.g. The Galileo's conclusion that the sun is at the centre of the solar system was not accepted by the church, and evolution is still rejected by some groups today.	philosophical beliefs but that has changed with time. Science is influenced either by a scientist's cultural or social values. Science does not depend on culture, e.g. Newton's laws are true in all countries, but some unproven theories may be accepted by some and rejected by others.	values as it is based on experimental evidence. Scientific facts are universally true.
Role of human creativity and imagination in science and the phases at which students believe that these play a role.	10.	Scientists usually *use imagination and creativity at all stages of their scientific investigations*. Scientists use their imagination and creativity *when planning* about the procedure they need to follow in their investigation, during the *collection of data*, analysis and *interpretation of data, formulation of variety of conclusions* and *presentation of their results*.	Scientists use imagination and/ or creativity in some stages but not in all.	Scientists do not use imagination and creativity at all, but they use the collected data or their personal experiences. Scientists base their conclusions on the gathered/collected data.

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Appendix J: Written practical examination

Van: *Surname:*		Voorletters: *Initials:*		Studentenommer: *Student Number:*								
Practical Exam: Written Section												
Datum: *Date*	**2014**	*mm*	*dd*	Praktikumsessie: *Practical session:*		Praktikum: *Practical:*	**PEWR**					
Handtekening van student: *Signature of student:*				Groepnommer: *Group number:*		Punt (/60): *Mark (/60):*						

1. A student that has just measured the "voltage" of a car battery, states that he now wants to measure the "amps" of the battery by setting the multimeter to the "10 A" range, and connecting the wires directly to the battery. What will happen? Explain in detail, by referring to the properties of an "ideal" ammeter.

____

____

____

[4]

2. In an experiment similar to the one you did, 1000 cubes, each with one side painted red were cast on the ground, and all the cubes with the red face upwards were removed. The remaining cubes were then collected and counted. Hereafter, the process was repeated a number of times with the remaining cubes, and each time the cubes with the red side facing upwards, were removed.

a) According to the theory, the number of cubes remaining, N_T, after throw number T is given by $N_T = N_0 \times e^{-kT}$ where N_0 is the original number of cubes and k is a constant. Assume that the cubes are identical and that the probability of a cube landing red face up is 1/6, and calculate the theoretical value of k.

____

____

____

[4]

b) What does the term "half life" refer to in an exponential decay process?

____

____

[2]

3. a) In the *Simple Harmonic Motion* experiment, the force that the spring exerted on the support was measured as a function of time. How could this be related to the position of the mass hanging from the spring?

____

____

____

[2]

b) State two methods according to which the spring constant of a spring may be determined. (Just state what independent and dependent quantities need to be measured, you don't have to give formulas.)

____

____

____

____

[4]

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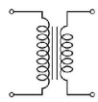
4. In the *Current Balance* experiment, the force on a current carrying conductor in a magnetic field was measured. Draw a rough sketch of the current balance, as viewed from the side. Ensure that you show the current carrying conductor, the region where the magnetic field is, the two adjustments that are made during the measurements as well as any other important working parts. Use the sketch to explain how the current balance was used to determine the force on a conductor. You do not have to show any formulas or do any derivation – just explain what parts of the current balance were adjusted, what direct measurements were taken from the current balance and what physical principles were involved. (Note: Explain how the *current balance* works, not the electromagnetic theory explaining the force on a conductor.)

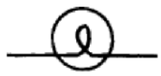
[10]

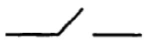
5. Draw a circuit diagram of an AC power supply, connected to the primary of a transformer and a light bulb in series with a switch, connected to the secondary of the transformer. Also, add voltmeters and ammeters required to measure voltage and current in both the primary as well as the secondary circuit of the transformer.

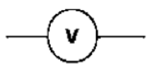
You may use the following symbols:

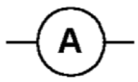
AC Source: 

Transformer: 

Light bulb: 

Switch: 

Voltmeter: 

Ammeter: 

[8]

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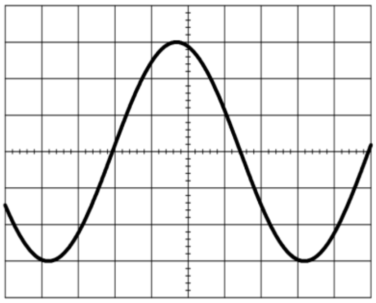
6. On the right is a sketch of the display on an oscilloscope. The time base was set to 2 ms/div and the vertical amplifier to 500 mV/div. Determine the amplitude and the frequency of the signal. Show your calculations in detail, so that it is clear you understand what you are doing (and that you may receive partial credit, should you make a mistake).



[5]

7. a) What does the "Trigger" control of the oscilloscope do and why is it useful?

[3]

b) Explain what "trigger level" and "trigger slope" refer to.

[2]

8. A student measures the voltage across and the current through a capacitor for different frequencies. His results are shown in the table below:

Frequency (Hz)	Voltage (V)	Current (mA)	$X_C = V/I$ (Ω)		
200	2.000	3.201			
400	2.000	6.002			
800	2.000	12.81			
1200	2.000	18.04			
1600	2.000	25.6			

a) According to the theory, the capacitive reactance is given by $X_C = 1/(2\pi f C)$. What quantity should be plotted as a function of f in order to obtain a linear graph? Show how this follows from the quoted equation.

[3]

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b) Plot the experimental points on the graph envisaged in part (a) on the graph paper below. Ensure that your graph conforms to the requirements of a scientific graph. (Two pieces of graph paper are supplied in case you want to re-draw your graph. If you use both, please clearly indicate which one you want marked.)

[10]

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c) Calculate the capacitance of the capacitor from your graph. Clearly show how you did this.

[4]

9) Questions on the nature of science: These are bonus marks – any reasonable attempt to answer them gets full marks!

a) Based on your experience in the practicals, do you believe that scientists use imagination and creativity when analysing and drawing conclusions from the data like you did in these practicals? Answer yes or no and explain your answer.

[2]

b) We talk about "Ohm's law" (that states $V = I \times R$) and the "atomic theory of matter" which states that all matter is made up of atoms. Using these as examples, explain what the difference between a law and a theory is.

[2]

<END>

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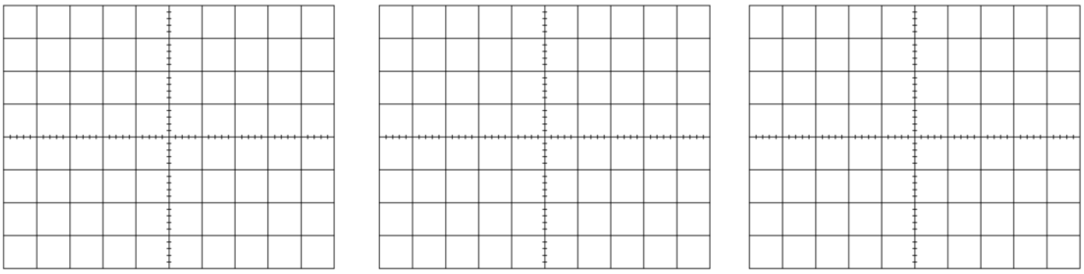
Appendix K: Hands-on practical examination

Van: *Surname:*		Voorletters: *Initials:*		Studentenommer: *Student Number:*			
Practical Exam: Oscilloscope							
Datum: *Date*	**2014**	*mm*	*dd*	Praktikumsessie: *Practical session:*		Praktikum: *Practical:*	**PEOA**
Handtekening van student: *Signature of student:*				Groepnommer: *Group number:*		Mark (/10): *Mark (/10):*	

On the desk in front of you, there should be an oscilloscope connected to an "unknown" signal source. Please complete the following tasks.

1. Switch the oscilloscope on and adjust the controls of the oscilloscope to display a stable image of a complete single cycle of the "unknown" sine wave. (Zoom in as far as possible, so that a single cycle is visible). Draw a sketch of the waveform displayed (three grids shown, in case you make a mistake). You may ask the technical assistant for help, but it will cost you marks:



(4)

Time base setting (incl. units!): ____(2)

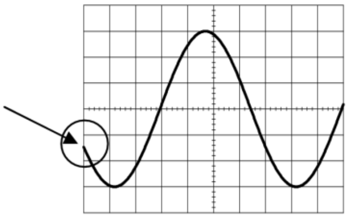
Vertical scale setting (incl. units!): ____(2)

TA: Indicate help given below: (One mark lost for every item.)

Help: Turning oscilloscope on and getting a beam / general setup. (–1)
Help: Setting time base (–1)
Help: Setting vertical scale (–1)
Help: Setting trigger (–1)

[8]

2. Set up the trigger of the oscilloscope so that your sweep starts at the point on the sine wave indicated on the sketch. Call your technical assistant to give you marks according to the picture on the oscilloscope.



Marks: Trigger level correct (1)

Marks: Trigger phase correct (1)

[2]

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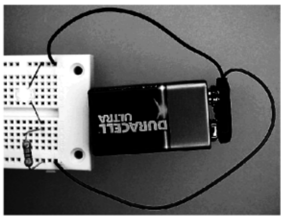
Van: *Surname:*		Voorletters: *Initials:*		Studentenommer: *Student Number:*	
Practical Exam: Multimeter					
Datum: *Date*	**2014** *mm* *dd*	Praktikumsessie: *Practical session:*		Praktikum: *Practical:*	**PEMA**
Handtekening van student: *Signature of student:*		Groepnommer: *Group number:*		Mark (/10): *Mark (/10):*	

On the desk in front of you, there should a circuit containing an LED (light emitting diode).

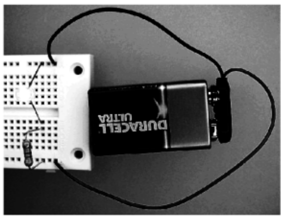
1. On the photos below, indicate clearly how you would connect the multimeter to measure the voltage across the diode.

Use the multimeter to measure the voltage across the diode as accurately as possible and report it (with units!) in the space below:

____ [4]

2. On the photos below, indicate how you would connect the multimeter to measure the current through the diode.

Use the multimeter to measure the current through the diode as accurately as possible, and report it (with units!) in the space below:

____ [4]

3. Use the multimeter to measure the resistance of the "unknown" resistor as accurately as possible and report it (with units!) in the space below. Also write down the letter code attached to the resistor.

____ [2]

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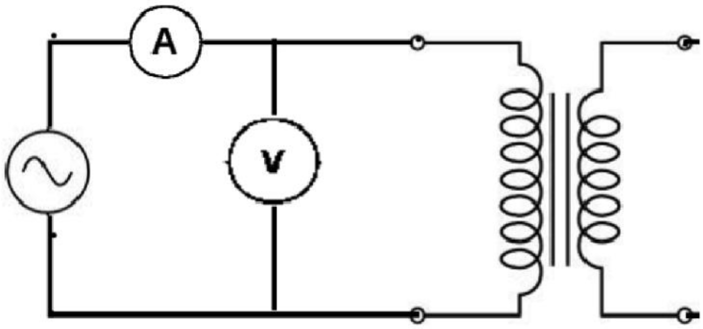
Van: *Surname:*		Voorletters: *Initials:*		Studentenommer: *Student Number:*			
Practical Exam: Transformer							
Datum: *Date*	**2014**	*Mm*	*dd*	Praktikumsessie: *Practical session:*		Praktikum: *Practical:*	**PETR**
Handtekening van student: *Signature of student:*				Groepnommer: *Group number:*		Mark (/10): *Mark (/10):*	

On the desk in front of you, there should be a voltmeter, ammeter, an AC voltage source and a transformer. Build the following circuit that can be used to measure the voltage across and the current through the primary of the transformer when it is connected to an AC source.

(Do not turn the power on – just build the circuit!)

Please ask your TA to check your circuit and allocate marks.



Marking (Done by TA at setup):

No help needed	(2)
Signal generator connected correctly	(2)
Voltmeter connected correctly	(2)
Ammeter connected correctly	(2)
Transformer / inductor connected correctly	(2)

[10]

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Appendix L: List of comparative studies

Note: All the highlighted studies were used in the current study

Literature review A: Studies in which either intervention was done followed by the use of VNOS questionnaire as either a single study or a pre/post-test.

						Agree			Disagree			
Summary	**Reference**	**Instrument**	**Subjects**	**Intervention & Research question**	**Type**	**Good EN,OI,TN 64,38,32 %**	**Average IC 18%**	**Bad SM,TL,SC 10,8,8%**	**Much worse than us**	**Slightly worse than us**	**Slightly better than us**	**Much better than us**
The present study	Baloyi	VNOS-C	1st year BSc students, doing practicals with ER NOS questions	Control vs. Experimental. ERQ in practical, study effect of ERGI Practical activities	Post, experimental - control	EN,OI,TN 64,38,32 %	IC 18%	SM,TL,SC 10,8,8%	**Much worse than us**	**Slightly worse than us**	**Slightly better than us**	**Much better than us**
In a study with a group of 100 grade 10 learners in South Africa, Baloyi, Nordhoff, Meyer, Gaigher and Braun (2014) investigated relationships between learners' views about NOS and contextual factors. A modified Views on the Nature of Science questionnaire consisting of eleven open-ended questions adapted from VNOS-C by Lederman et al ., (2002) was used to examine learners" views on seven aspects of NOS. Findings showed that students demonstrated good understanding of EN, TN and SC but poor understanding of NM, OI, IC, and TL.	Baloyi, Nordhoff, Meyer, Gaigher and Braun (2014)	A modified Views on the Nature of Science questionnaire consisting of eleven open-ended questions adapted from VNOS-C	100 grade 10 learners	Science enrichment programme using inquiry activities	Single test	EN, TN		SC	NM, OI, IC, and TL			

In a study with 50 undergraduate science students, Vhurumuku (2010) investigated the influence of a short explicit-reflective Nature of Science Course on students' ideas about NOS at the University of the Western Cape in South Africa. Participants in this study completed both the pre- and post-intervention questionnaire containing questions which were selected and adapted from the Views of Nature of Science (VNOS) -Form C (Lederman *et al.,* 2002, p. 509). Results showed that participants performed better in TN (pre-test, 0%: post-test 84% Δ84 pp); difference and relationship between TL especially informed view that theories will never change into laws (pre-test, 0%: post-test 32% Δ32 pp), EN (pre-test,0%: post-test,16% Δ16 pp) and role of experiments in science in particular there are many ways including experimentation to generate scientific knowledge or NM (pre-test,6%: post-test,42% Δ36 pp).	Vhurumuku (2010)	VNOS) -Form C	50 undergraduate science students	explicit-reflective Nature of Science Course	Pre-post tests				EN,TN,TL	SM	
Ibrahim, Buffler and Lubben (2009) investigated the views on various aspects of NOS of 179 undergraduate physics students using six open-ended, written probes in South Africa. The researchers classified the four profiles that emerged from the data as ''modelers,''''experimenters,'' ''examiners,'' and ''discoverers,''. Results in this study indicated that modelers demonstrated informed views in all aspects of NOS: the nature of scientific knowledge (TN and EN), the origin of laws or theories, and the purpose of scientific experiments in relation to theories, the role of creativity in scientific experimentation (IC), the precedence of theoretical and experimental results, (TL).	Ibrahim, Buffler and Lubben (2009)	Views About Scientific Measurement questionnaire	179 undergraduate physics students	None	single-test	EN, TN	IC	TL			
In a study with 38 non-science majors, enrolled in a general education course named Food and the Body held in a local community college in Hong Kong, Leung, Wong and Yung (2015), used the Views about Science Questionnaire (containing questions extracted from VNOS-C), and a follow-up interview to assess participants' on NOS. The results indicated that particpants showed informed views in TN, (68%) and SC (32%). The results in this study are in agreement with the findings in the current study, in that students in the current study showed good performance in TN.	Leung, Wong and Yung (2015)	Views about Science Questionnaire (containing questions extracted from VNOS-C)	38 non-science majors enrolled in a general education course named Food and the Body	NOS instruction integrated in the course	Single	TN					SC

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In a study performed on 17 eleventh grade students in public high school in Ankara, Turkey, Nur and Fitnat (2015) examined the effects of NOS instruction with interactive historical vignette on students' views NOS and student development. The Views on the Nature of Science Questionnaire- form-C (VNOS-C) was used to evaluate participants' views of NOS before and after instruction. Results showed that the explicit-reflective approach to teaching of the chemical equilibrium unit enhanced students' understanding as reflected by the VNOS test. After the course, the percentage of students with informed views was TN (pre-test, 45%: post-test, 78% Δ 33 pp), SC (pre-test, 39%: post-test, 69% Δ30 pp), IC (pre-test, 67%: post-test, 90% Δ23 pp each) , EN (pre-test, 55%: post-test, 78% Δ23 pp each), OI (pre-test, 41%: post-test, 63% Δ22 pp), and TL (pre-test, 29%: post-test, 49% Δ20 pp).	Nur and Fitnat (2015)	VNOS-C	17, 11th grade students	ER teaching of electro-chemistry.	Pre-post, exp-control. Post test compared	TN	TL	EN	OI	SC
In a study with 220 the senior pre-service science and mathematics teachers in Turkey, Celik and Karatas (2014), investigated participants' views of NOS and to find out any relationships between their views and VNOS-C. The pre-service teachers were from departments of chemistry, physics, biology and mathematics in both Faculty of Education and Faculty of Science. In this study the results associated with the performance of pre-service teachers from Faculty of Science were considered as they are related to the findings in the current study. The results showed that pre-service teachers showed informed views in TN (7%), EN (24%), TL (24%), IC (97%) and SC (31%).	Celik and Karatas (2014)	VNOS-C	220 the senior pre-service science and mathematics teachers,	None Evaluate whether their views are associated with study subject in which the pre-service teachers participate.	Single test.			TN, EN	TL	IC, SC
In a study with 7 pre-service elementary science teachers in Turkey, Bilican, Cakiroglu, and Oztekin (2015) explored how different contextualized settings, combined with explicit reflective NOS intervention promote their views on NOS. The results showed that the professional development program assisted teachers to demonstrate substantial improvements in TN, EN, OI, SC, and TL.	Bilican, Cakiroglu, and Oztekin (2015)	modified version of VNOS-C	seven pre-service science teachers	Exp. refl. NOS intervention	Pre/post	EN, TN	TL,OI,SC			

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In a study with 219 grade 11 students in Beirut, Lebanon, Khishfe (2012) investigated the relationship of high school students'understandings about NOS aspects and their argumentation skills in relation to two controversial socioscientific issues. Participants were administered a Controversial Socioscientific Issues Questionnaire that consisted of two scenarios that addressed the controversial socioscientific issues about genetically modified food and water fluoridation. Results showed that Scenario I participants performed better than Scenario II particpants in TN (11% vs 5%), and EN (15% vs 12%) through the use of argumentation skills.	Khishfe (2012)	Controversial Socioscientific Issues Questionnaire	219 grade 11 students.	A Role for Counterargument and Contextual Factors	Pre/post			TN, EN
Akerson and Donnelly (2010) explored the influence of a 6-week Saturday science program that used explicit reflective instruction on K-2 students' views of NOS and how these views change at the end of the program in the US. The sample comprised of 18 kindergarden, grade 1 and grade 2 students of which 14 were male and 4 female. The participants were taught a variety of topics using an inquiry-based approach. The Views of Nature of Science Form D (VNOS-D), group discussions, copies of students" work and interviews at the end of the program were used to evaluate participants' views of NOS. Results showed that elementary students demonstrated informed views of OI, IC, and TN and to a lesser degree the subjective nature of NOS after using explicit reflective instruction in inquiry-based context.	Akerson and Donnelly (2010)	VNOS-D	18 kindergarden, grade 1 and grade 2 students of which 14 were male and 4 female.	influence of a 6-week Saturday science program that used explicit reflective instruction	pre- and post-instruction	TN, OI		
In a study with 17 undergraduate atmospheric science students in the US, Parker, Krockover, LaSher-Trapp, and Eichinger (2008) employed VNOS-C (Lederman *et al.,* 2002) to elicit and analyze partcipants' ideas about NOS. Results indicate that participants showed informed views on TL (20%), and IC (27%).	Parker, Krockover, LaSher-Trapp, and Eichinger (2008)	VNOS-C	17 undergraduate atmospheric science students	None	Single-test	IC	TL	
In a study with 15 prospective science teacher educators in the context of teacher education reform in Turkey, Irez (2006) used the VNOS-C (Views on Nature of Science Questionnaire, Form C) developed by Abd-El-Khalick (1998) to assess participants' conceptions about science. Results showed that teachers held naïve views on the NM and TN aspects of NOS after the course.	Irez (2006)	VNOS-C	15 prospective science teacher educators	of teacher education reform	Single test		NM	TN

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In an explicit learner-centred inquiry study with 79 learners in South Africa, Dekkers (2006) used questions adapted from VNOS-C by Lederman *et al.* (2002) .Students showed informed understanding of EN, SM, and IC.	Dekkers (2006)	questions adapted from VNOS-C	79 learners	explicit learner-centred inquiry	Single test	EN	IC	SM				
In a study with two science teachers, Ogunniyi (2006) examines the effectiveness of a NOS course in enhancing teachers' understanding of selected characteristics of NOS in South Africa. A Nature of Science Questionnaire was administered at the start and again at the end of the course to evaluate participants' views of NOS. Results showed that participants developed an informed view on SC through the use of a discursive course as an example of explicit reflective approach.	Ogunniyi (2006)	A Nature of Science Questionnaire	two science teachers	a discursive course as an example of explicit reflective approach	Pre-post			SC				
Yalçinoğlu and Anagün (2012) investigated the development of elementary science teachers' understandings of NOS as they were taught with an explicit approach in a NOS course in Turkey. The participants' views of NOS were evaluated with Views of Nature of Science Questionnaire form C (VNOS-C) before and after the intervention. Results indicated that 29 pre-service elementary science teachers performed well in SC (pre-test, 5%: post-test, 24% Δ 19 pp), TN (pre-test, 8%: post-test, 24% Δ 16pp), OI (pre-test, 5%: post-test, 20% Δ 15 pp), IC (pre-test, 18%: post-test, 28% Δ 10 pp), and did not do well in TL (pre-test,0 %: post-test, 0% Δ 0 pp) by an explicit approach.	Yalçinoğlu and Anagün (2012)	VNOS-C	29 pre-service elementary science teachers	explicit approach in a NOS course	Pre/post		OI, 43%;		TL, 0%		TN, 55%	SC, 50%; IC,79%
A study with 20 teachers, Morrison, Raab and Ingram (2009) explore how elementary teachers may differ from secondary teachers in their views about NOS, a professional development experience using explicit reflective instruction on NOS. The Views of Nature of Science Questionnaire-Form B [VNOS-B] (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002) was employed in order to assess participants' views on the targeted features of NOS at the beginning and at the end of the 2-week course. At the end of the course, teachers showed informed views of NOS in	Morrison, Raab and Ingram (2009)	VNOS-B	20 teachers	a professional development experience using explicit reflective instruction on NOS	Pre-post tests			SC, 10%	EN, 8%; TL, 3; OI, 8%	IC, 25%		

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In a study with 33 pre-service teachers in the Middle East, Baraz (2012) investigated the effect of using metacognitive strategies embedded in explicit–reflective NOS instruction to improve NOS understanding of pre-service science teachers. Participants were divided into two groups namely comparison and intervention group. Explicit reflective NOS instruction was used in both groups, but metacognitive strategies additionally used in intervention group. Metacognitive Awareness Inventor (Schraw & Dennison, 1994) and Views of Nature of Science Questionnaire (VNOS-C) (Lederman *et al.,* 2001) were used as a pre-test–post-test, at the beginning and at the end of the study, to assess participants' views of NOS. Results demonstrated that explicit reflective NOS instruction enhanced the development of understanding of NOS in both groups. However, results also showed that metacognitive strategies improved the metacognitive awareness of intervention group participants. The intervention group also showed informed views in EN (E47:C17 Δ30 pp), TN (E33:C11 Δ22 pp), OI (E47:C22 Δ25 pp), IC (E67:C56 Δ 11 pp), TL (E73:C 50Δ23 pp), SC (E33:C22 Δ11 pp).	Baraz (2012)	Metacognitive Awareness Inventor (Schraw & Dennison, 1994) and Views of Nature of Science Questionnaire (VNOS-C) (Lederman *et al.,* 2001)	33 pre-service teachers	Explicit reflective NOS instruction	Pre-post	EN, and OI	SC	TN		IC,TL
In a study with 36 prospective science teachers, Celik and Bayrakceken (2012) found that participants performed well in tentative NOS (72%), scientific theories and laws (58%), differences between observation and inference (49%), through activity-based explicit approach. Participants did not do well in social and cultural influences on science (25%), and creativity and imagination in science (17%).	Celik and Bayrakceken (2012)	modified questionnaire using VNOS B and C	36 prospective science teachers	Science, Technology and Society" course	Pre-post test	TN,OI			SC,IC	TL

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Abd-El-Khalick and Akerson (2009) investigated the influence of training in, and use of, metacognitive strategies on the development of 49 prospective elementary teachers' views of NOS in the US. Participants were randomly assigned to an intervention group and a comparison group. The participants' conceptions of the target aspects of NOS and their metacognitive awareness were assessed using the VNOS-C (Lederman *et al.,* 2002). Students in both groups were engaged with explicit-reflective NOS instruction in two sections of an elementary science methods course, which focused on the EN, TN, OI and IC NOS aspects. Results indicated that significantly more students in the intervention group expressed more informed views of EN (pre-test 46%; post-test 68%, Δ22 pp), TN (pre-test 50%; post-test 72%, Δ22 pp), OI (pre-test 41%; post-test 64%, Δ23 pp)and IC(pre-test 55%; post-test 56 %, Δ1 pp).	Abd-El-Khalick and Akerson (2009)	VNOS-C	49 prospective elementary teachers	explicit-reflective NOS	Pre-post test, intervention group vs comparison group	EN, 57%			OI, 53%	TN, 61%; TL, 56%
In an explicit instruction and reflection study with 13 secondary pre-service teachers in the US, Schwartz, Lederman, and Crawford (2004), assessed Interns' NOS views in a pre/post format using the Views of Nature of Science questionnaire, [VNOS-C] and interviews. Results found showed informed views in TN, IC, SC, EN, TL and OI.	Schwartz, Lederman, and Crawford (2004),	VNOS-C	13 secondary pre-service teachers	an explicit instruction and reflection study	Pre-post	EN, TN, OI	IC	TL,SC		
In a study with 10 grade 10-11 students in the US, Bell, Blair, Crawford, and Lederman (2003) used the Views of Nature of Science, Form B both before and after their apprenticeship to examine the impact of an 8-week science apprenticeship program on a group of high-ability secondary students' understandings of NOS and scientific inquiry. Also, semi-structured interviews allowed students to elaborate on their responses in the questionnaire and further develop their understanding of NOS. Although most students did appear to gain knowledge about the processes of scientific inquiry, their conceptions about key aspects of the nature of science (EN, TL, TN and IC) remained virtually unchanged.	Bell, Blair, Crawford, and Lederman (2003)	VNOS-B	10 grade 10-11 students	apprenticeship to examine the impact of an 8-week science apprenticeship program	Pre-post	EN, TN	IC	TL		

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In an explicit, reflective approach to teach about NOS in a physics course in the US, Abd-El-Khalick (2001) investigated the ability of participants to apply the acquired NOS understandings into their instructional practice. An open-ended questionnaire (Abd-El-Khalick, 1998) was used to assess participants' views of NOS at the beginning and at the conclusion of the programme.The results showed extensive changes in TN, EN, OI, and IC. The findings showed that participants were able to translate NOS understandings in the context of issue of more familiar content (e.g. atomic structure covered in the course) than unfamiliar content (e.g. dinosaur extinction).	Abd-El-Khalick (2001)	An open-ended questionnaire	30 elemantary majors	explicit, reflective approach to NOS in a physics course	Pre-post	EN,TN,OI	IC			
In an explicit, reflective instructional approach study with 28 undergraduate students, Abd-El- Khalick and Akerson (2004) found that participants showed informed views in IC (68%), TL (64%), NM (54%), TN (53%), OI (50%), and EN (42%).	Abd-El-Khalick and Akerson (2004)	VNOS–B	28 undergraduate students	After an elementary science methods course	Pre-post test		TN		EN	TL, IC,OI
In a program designed to improve 63 pre-service teachers' understanding of NOS in Taiwan, Lin and Chen (2002) examined benefits of teaching chemistry through history. A modified version of VOSTS (Aikenhead & Ryan, 1992) was used to assess the students'conception of the nature of science.The results demonstrated that participants showed significant improvement of knowledge of IC, the theory-bound nature of observations, and TL. The authors claimed that helping teachers learn how to use the history of science in science instruction positively influenced the teachers' understandings of NOS.	Lin and Chen (2002)	modified version of VOSTS	63 preservice teachers	teacher preparation program	Control vs experimental groups		IC	TL		

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Çıbık, (2016) compared the change of (3rd grade undergraduate students) pre-service science teachers' views about the nature of scientific knowledge through Project-Based History and NOS training and Conventional Method at an education faculty in Turkey. The sample in this study consisted of two groups: experimental and control. Student Understanding of Science and Scientific Inquiry questionnaire was applied to both groups as pre-test and post-test. The results showed that the experimental group performed better than the control group in five aspects of NOS: OI (pre-test 7%: post-test 22%, Δ15 pp), TN (pre-test 6%: post-test 21% Δ15%), TL (pre-test 7 %: post-test 21%, Δ14 pp), SC (pre-test 5%: post-test 23%, Δ18%), IC (pre-test 6 %: post-test 20%, Δ14 pp), and NM (pre-test 3.4%: post-test 24 %, Δ21 pp). Conversely the control group did better than the experimental group in TL and SC.	Çıbık, (2016)	Student Understanding of Science and Scientific Inquiry questionnaire	3rd grade undergraduate students/ pre-service science teachers	Project-Based History and NOS training and Conventional Method	Pre-post test, experimental and control		TL 14%, SC, 14%, NM, 14%	IC, 13 %	OI 15%, TN, 15%	
Sharif and Hasan (2012) used 76 tenth-grade students in Dubai to investigate students' views of NOS. These researchers further explored the impact of guided-inquiry of instruction in teaching the environmental biology subject and NOS aspects with students. Participants in this study were assigned to experimental and control groups. The experimental group was taught using the guided inquiry instruction during theoretical classes and laboratory activities. The control group was taught using the traditional strategies, without incorporating the guided inquiry instruction and the science process-skills. Students' NOS views were assessed using a NOS scale (NOSS) questionnaire using questions extracted from the articles; Wenning (2006) and Iqbal *et al.* (2009), and the doctorate thesis for Larson-Miller (2011). Differences in the total average scores between pre- and post-NOS tests showed that the experimental group performed better than the control group in NM (pre-test 72%: post-test 86%, Δ14 pp) and TL (pre-test 72%: post-test 72% Δ0 pp).	Sharif and Hasan (2012)	NOS scale (NOSS) questionnaire	76 tenth-grade students	guided-inquiry of instruction in teaching the environmental biology subject and NOS aspects	pre- and post-NOS tests, control vs experimental groups					NM, 61%; TL, 66%

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Kim and Irving (2010) explores the effectiveness of the contextualized history of science on student learning of NOS and genetics content knowledge (GCK) in high school biology classrooms in the US and provides an exemplar for teachers on how to utilize history of science in genetics instruction; and suggests a modified concept mapping assessment tool for both NOS and GCK. A quasi-experimental control group research design was utilized with pre-tests, post-tests, and delayed post-tests. The participants were 31 10th-grade high school Biology students that were also assigned to experimental group (16 students) and a control group (17 students). Participants' views of NOS were assessed using several methods including NOS Terms Definition with Concept Mapping, the View of Nature of Science-Form C (VNOS-C) developed by AbdEl-Khalick in 1998 and semi-structured interviews. The results indicated that students in the experimental group developed better understanding of NOS after the intervention in EN (C0%:E23%, Δ23 pp),TN (C0%:E2%, Δ2 pp),IC (C0%:E16%, Δ16 pp), SC (C5%:E18%, Δ13 pp),OI (C0%:E11%, Δ11 pp) and TL (C6%:E16%,Δ10 pp).	Kim and Irving.(2010)	VNOS-C	31 10th-grade high school Biology students	contextualized history of science on student learning of NOS	Pre-post tests, control vs experimental groups	EN	TL, SC	IC, TN, OI	
Yacoubian and BouJaoude (2010) investigated the effect of reflective discussions following inquiry-based laboratory activities on 38 grade six Lebanese students' views of NOS. The study used a pre–post test control-group design and focused on collecting mainly qualitative data. During each laboratory session, students worked in groups of two. Later, experimental group students answered open-ended questions about NOS then engaged in reflective discussions about NOS. Control group students answered open-ended questions about the content of the laboratory activities then participated in discussions of results of these activities. Results indicated that explicit and reflective discussions following inquiry-based laboratory activities enhanced students' views of the target NOS aspects:.	Yacoubian and BouJaoude (2010)	open-ended questions about NOS	38 grade six Lebanese students	reflective discussions following inquiry-based laboratory activities	pre–post test control vs experimental groups		SC, 15%	TN, 11 %	EN, 26%

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Literature review B: Studies in which either intervention was done followed by the use of VNOS questionnaire as a pre-post test. (No control and experimental groups).

						Agree			Disagree			
Summary	**Reference**	**Instrument**	**Subjects**	**Intervention & Research question**	**Type**	**Good EN,OI,TN 64,38,32 %**	**Average IC 18%**	**Bad SM,TL,SC 10,8,8%**	**Much worse than us**	**Slightly worse than us**	**Slightly better than us**	**Much better than us**
The present study	Baloyi	VNOS-C	1st year BSc students, doing practicals with ER NOS questions	Control vs. Experimental. ERQ in practical, study effect of ERGI Practical activities	Post, experimental - control	**Good EN,OI,TN 64,38,32%**	**Average IC 18%**	**Bad SM,TL,SC 10,8,8%**	**Much worse than us**	**Slightly worse than us**	**Slightly better than us**	**Much better than us**
In a study with a group of 100 grade 10 learners in South Africa, Baloyi, Nordhoff, Meyer, Gaigher and Braun (2014) investigated relationships between learners' views about NOS and contextual factors. A modified Views on the Nature of Science questionnaire consisting of eleven open-ended questions adapted from VNOS-C by Lederman et al ., (2002) was used to examine learners" views on seven aspects of NOS. Findings showed that students demonstrated good understanding of EN, TN and SC but poor understanding of NM, OI, IC, and TL.	Baloyi, Nordhoff, Meyer, Gaigher and Braun (2014)	A modified Views on the Nature of Science questionnaire consisting of eleven open-ended questions adapted from VNOS-C	100 grade 10 learners	Science enrichment programme using inquiry activities	Single test	EN, TN		SC	NM, OI, IC, and TL			

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In a study with 33 pre-service teachers in the Middle East, Baraz (2012) investigated the effect of using metacognitive strategies embedded in explicit–reflective NOS instruction to improve NOS understanding of pre-service science teachers. Participants were divided into two groups namely comparison and intervention group. Explicit reflective NOS instruction was used in both groups, but metacognitive strategies additionally used in intervention group. Metacognitive Awareness Inventor (Schraw & Dennison, 1994) and Views of Nature of Science Questionnaire (VNOS-C) (Lederman *et al.,* 2001) were used as a pre-test–post-test, at the beginning and at the end of the study, to assess participants' views of NOS. Results demonstrated that explicit reflective NOS instruction enhanced the development of understanding of NOS in both groups. However, results also showed that metacognitive strategies improved the metacognitive awareness of intervention group participants. The intervention group also showed informed views in EN (E47:C17 Δ30 pp), TN (E33:C11 Δ22 pp), OI (E47:C22 Δ25 pp), IC (E67:C56 Δ 11 pp), TL (E73:C 50Δ23 pp), SC (E33:C22 Δ11 pp).	Baraz (2012)	Metacognitive Awareness Inventor (Schraw & Dennison, 1994) and Views of Nature of Science Questionnaire (VNOS-C) (Lederman *et al.,* 2001)	33 pre-service teachers	Explicit reflective NOS instruction	Pre-post	EN,TN, OI			TL,SC
In a study with 50 undergraduate science students, Vhurumuku (2010) investigated the influence of a short explicit-reflective Nature of Science Course on students' ideas about NOS at the University of the Western Cape in South Africa. Participants in this study completed both the pre- and post-intervention questionnaire containing questions which were selected and adapted from the Views of Nature of Science (VNOS) -Form C (Lederman *et al.,* 2002, p. 509). Results showed that participants performed better in TN (pre-test, 0%: post-test 84% Δ84 pp); difference and relationship between TL especially informed view that theories will never change into laws (pre-test, 0%: post-test 32% Δ32 pp), EN (pre-test,0%: post-test,16% Δ16 pp) and role of experiments in science in particular there are many ways including experimentation to generate scientific knowledge or NM (pre-test,6%: post-test,42% Δ36 pp).	Vhurumuku (2010)	VNOS) -Form C	50 undergraduate science students	explicit-reflective Nature of Science Course	Pre-post tests		EN,TN,TL	SM	

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Ibrahim, Buffler and Lubben (2009) investigated the views on various aspects of NOS of 179 undergraduate physics students using six open-ended, written probes in South Africa. The researchers classified the four profiles that emerged from the data as ‘‘modelers,’’‘‘experimenters,’’ ‘‘examiners,’’ and ‘‘discoverers,’’. Results in this study indicated that modelers demonstrated informed views in all aspects of NOS: the nature of scientific knowledge (TN and EN), the origin of laws or theories, and the purpose of scientific experiments in relation to theories, the role of creativity in scientific experimentation (IC), the precedence of theoretical and experimental results, (TL).	Ibrahim, Buffler and Lubben (2009)	Views About Scientific Measurement questionnaire	179 undergraduate physics students	None	single-test	EN, TN	IC	TL			
In an explicit learner-centred inquiry study with 79 learners in South Africa, Dekkers (2006) used questions adapted from VNOS-C by Lederman *et al.* (2002) .Students showed informed understanding of EN, SM, and IC.	Dekkers (2006)	questions adapted from VNOS-C	79 learners	explicit learner-centred inquiry	Single test	EN	IC	SM			
In a study with two science teachers, Ogunniyi (2006) examines the effectiveness of a NOS course in enhancing teachers' understanding of selected characteristics of NOS in South Africa. A Nature of Science Questionnaire was administered at the start and again at the end of the course to evaluate participants’ views of NOS. Results showed that participants developed an informed view on SC through the use of a discursive course as an example of explicit reflective approach.	Ogunniyi (2006)	A Nature of Science Questionnaire	two science teachers	a discursive course as an example of explicit reflective approach	Pre-post			SC			
Yalçinoğlu and Anagün (2012) investigated the development of elementary science teachers’ understandings of NOS as they were taught with an explicit approach in a NOS course in Turkey. The participants’ views of NOS were evaluated with Views of Nature of Science Questionnaire form C (VNOS-C) before and after the intervention. Results indicated that 29 pre-service elementary science teachers performed well in SC (pre-test, 5%: post-test, 24% Δ 19 pp), TN (pre-test, 8%: post-test, 24% Δ 16pp), OI (pre-test, 5%: post-test, 20% Δ 15 pp), IC (pre-test, 18%: post-test, 28% Δ 10 pp), and did not do well in TL (pre-test,0 %: post-test, 0% Δ 0 pp) by an explicit approach.	Yalçinoğlu and Anagün (2012)	VNOS-C	29 pre-service elementary science teachers	explicit approach in a NOS course	Pre/post		OI, 43%;		TL, 0%	TN, 55%	SC, 50%; IC,79%

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A study with 20 teachers, Morrison, Raab and Ingram (2009) explore how elementary teachers may differ from secondary teachers in their views about NOS, a professional development experience using explicit reflective instruction on NOS. The Views of Nature of Science Questionnaire-Form B [VNOS-B] (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002) was employed in order to assess participants' views on the targeted features of NOS at the beginning and at the end of the 2-week course. At the end of the course, teachers showed informed views of NOS in	Morrison, Raab and Ingram (2009)	VNOS-B	20 teachers	a professional development experience using explicit reflective instruction on NOS	Pre-post tests			SC, 10%	EN, 8%; TL,3; OI, 8%	IC, 25%		
In a study with 36 prospective science teachers, Celik and Bayrakceken (2012) found that participants performed well in tentative NOS (72%), scientific theories and laws (58%), differences between observation and inference (49%), through activity-based explicit approach. Participants did not do well in social and cultural influences on science (25%), and creativity and imagination in science (17%).	Celik and Bayrakceken (2012)	modified questionnaire using VNOS B and C	36 prospective science teachers	Science, Technology and Society" course	Pre-post test	TN,OI					SC,IC	TL
Abd-El-Khalick and Akerson (2009) investigated the influence of training in, and use of, metacognitive strategies on the development of 49 prospective elementary teachers' views of NOS in the US. Participants were randomly assigned to an intervention group and a comparison group. The participants' conceptions of the target aspects of NOS and their metacognitive awareness were assessed using the VNOS-C (Lederman *et al.*, 2002). Students in both groups were engaged with explicit-reflective NOS instruction in two sections of an elementary science methods course, which focused on the EN, TN, OI and IC NOS aspects. Results indicated that significantly more students in the intervention group expressed more informed views of EN (pre-test 46%; post-test 68%, Δ22 pp), TN (pre-test 50%; post-test 72%, Δ22 pp), OI (pre-test 41%; post-test 64%, Δ23 pp)and IC(pre-test 55%; post-test 56 %, Δ1 pp).	Abd-El-Khalick and Akerson (2009)	VNOS-C	49 prospective elementary teachers	explicit-reflective NOS	Pre-post test, intervention group vs comparison group	EN, 57%					OI, 53%	TN, 61%; TL, 56%
In an explicit instruction and reflection study with 13 secondary pre-service teachers in the US, Schwartz, Lederman, and Crawford (2004), assessed Interns' NOS views in a pre/post format using the Views of Nature of Science questionnaire, [VNOS-C] and interviews. Results found showed informed views in TN, IC, SC, EN, TL and OI.	Schwartz, Lederman, and Crawford (2004),	VNOS-C	13 secondary pre-service teachers	an explicit instruction and reflection study	Pre-post	EN, TN, OI	IC	TL,SC				

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In a study with 10 grade 10-11 students in the US, Bell, Blair, Crawford, and Lederman (2003) used the Views of Nature of Science, Form B both before and after their apprenticeship to examine the impact of an 8-week science apprenticeship program on a group of high-ability secondary students' understandings of NOS and scientific inquiry. Also, semi-structured interviews allowed students to elaborate on their responses in the questionnaire and further develop their understanding of NOS. Although most students did appear to gain knowledge about the processes of scientific inquiry, their conceptions about key aspects of the nature of science (EN, TL, TN and IC) remained virtually unchanged.	Bell, Blair, Crawford, and Lederman (2003)	VNOS-B	10 grade 10-11 students	apprenticeship to examine the impact of an 8-week science apprenticeship program	Pre-post	EN, TN	IC	TL		
In an explicit, reflective approach to teach about NOS in a physics course in the US, Abd-El-Khalick (2001) investigated the ability of participants to apply the acquired NOS understandings into their instructional practice. An open-ended questionnaire (Abd-El-Khalick, 1998) was used to assess participants' views of NOS at the beginning and at the conclusion of the programme.The results showed extensive changes in TN, EN, OI, and IC. The findings showed that participants were able to translate NOS understandings in the context of issue of more familiar content (e.g. atomic structure covered in the course) than unfamiliar content (e.g. dinosaur extinction).	Abd-El-Khalick (2001)	An open-ended questionnaire	30 elemantary majors	explicit, reflective approach to NOS in a physics course	Pre-post	EN,TN,OI	IC			
In an explicit, reflective instructional approach study with 28 undergraduate students, Abd-El- Khalick and Akerson (2004) found that participants showed informed views in IC (68%), TL (64%), NM (54%), TN (53%), OI (50%), and EN (42%).	Abd-El-Khalick and Akerson (2004)	VNOS–B	28 undergraduate students	After an elementary science methods course	Pre-post test		TN		EN	TL, IC,OI
In a program designed to improve 63 pre-service teachers' understanding of NOS in Taiwan, Lin and Chen (2002) examined benefits of teaching chemistry through history. A modified version of VOSTS (Aikenhead & Ryan, 1992) was used to assess the students'conception of the nature of science.The results demonstrated that participants showed significant improvement of knowledge of IC, the theory-bound nature of observations, and TL. The authors claimed that helping teachers learn how to use the history of science in science instruction positively influenced the teachers' understandings of NOS.	Lin and Chen (2002)	modified version of VOSTS	63 preservice teachers	teacher preparation program	Control vs experimental groups		IC	TL		

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Çıbık, (2016) compared the change of (3rd grade undergraduate students) pre-service science teachers' views about the nature of scientific knowledge through Project-Based History and NOS training and Conventional Method at an education faculty in Turkey. The sample in this study consisted of two groups: experimental and control. Student Understanding of Science and Scientific Inquiry questionnaire was applied to both groups as pre-test and post-test. The results showed that the experimental group performed better than the control group in five aspects of NOS: OI (pre-test 7%: post-test 22%, Δ15 pp), TN (pre-test 6%: post-test 21% Δ15%), TL (pre-test 7 %: post-test 21%, Δ14 pp), SC (pre-test 5%: post-test 23%, Δ18%), IC (pre-test 6 %: post-test 20%, Δ14 pp), and NM (pre-test 3.4%: post-test 24 %, Δ21 pp). Conversely the control group did better than the experimental group in TL and SC.	Çıbık, (2016)	Student Understanding of Science and Scientific Inquiry questionnaire	3rd grade undergraduate students/ pre-service science teachers	Project-Based History and NOS training and Conventional Method	Pre-post test, experimental and control	TL 14%, SC, 14%, NM, 14%	IC, 13%	OI 15%, TN, 15%	
Sharif and Hasan (2012) used 76 tenth-grade students in Dubai to investigate students' views of NOS. These researchers further explored the impact of guided-inquiry of instruction in teaching the environmental biology subject and NOS aspects with students. Participants in this study were assigned to experimental and control groups. The experimental group was taught using the guided inquiry instruction during theoretical classes and laboratory activities. The control group was taught using the traditional strategies, without incorporating the guided inquiry instruction and the science process-skills. Students' NOS views were assessed using a NOS scale (NOSS) questionnaire using questions extracted from the articles; Wenning (2006) and Iqbal *et al.* (2009), and the doctorate thesis for Larson-Miller (2011). Differences in the total average scores between pre- and post-NOS tests showed that the experimental group performed better than the control group in NM (pre-test 72%: post-test 86%, Δ14 pp) and TL (pre-test 72%: post-test 72% Δ0 pp).	Sharif and Hasan (2012)	NOS scale (NOSS) questionnaire	76 tenth-grade students	guided-inquiry of instruction in teaching the environmental biology subject and NOS aspects	pre- and post-NOS tests, control vs experimental groups				NM, 61%; TL, 66%

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Kim and Irving (2010) explores the effectiveness of the contextualized history of science on student learning of NOS and genetics content knowledge (GCK) in high school biology classrooms in the US and provides an exemplar for teachers on how to utilize history of science in genetics instruction; and suggests a modified concept mapping assessment tool for both NOS and GCK. A quasi-experimental control group research design was utilized with pre-tests, post-tests, and delayed post-tests. The participants were 31 10th-grade high school Biology students that were also assigned to experimental group (16 students) and a control group (17 students). Participants' views of NOS were assessed using several methods including NOS Terms Definition with Concept Mapping, the View of Nature of Science-Form C (VNOS-C) developed by AbdEl-Khalick in 1998 and semi-structured interviews. The results indicated that students in the experimental group developed better understanding of NOS after the intervention in EN (C0%:E23%, Δ23 pp),TN (C0%:E2%, Δ2 pp),IC (C0%:E16%, Δ16 pp), SC (C5%:E18%, Δ13 pp),OI (C0%:E11%, Δ11 pp) and TL (C6%:E16%,Δ10 pp).	Kim and Irving.(2010)	VNOS-C	31 10th-grade high school Biology students	contextualized history of science on student learning of NOS	Pre-post tests, control vs experimental groups	EN			TL, SC	IC, TN,OI		
Yacoubian and BouJaoude (2010) investigated the effect of reflective discussions following inquiry-based laboratory activities on 38 grade six Lebanese students' views of NOS. The study used a pre–post test control-group design and focused on collecting mainly qualitative data. During each laboratory session, students worked in groups of two. Later, experimental group students answered open-ended questions about NOS then engaged in reflective discussions about NOS. Control group students answered open-ended questions about the content of the laboratory activities then participated in discussions of results of these activities. Results indicated that explicit and reflective discussions following inquiry-based laboratory activities enhanced students' views of the target NOS aspects:.	Yacoubian and BouJaoude (2010)	open-ended questions about NOS	38 grade six Lebanese students	reflective discussions following inquiry-based laboratory activities	pre–post test control vs experimental groups				SC, 15%	TN, 11%	EN, 26%	
In a study with 20 teachers, Morrison, Raab and Ingram (2009) explore how elementary teachers may differ from secondary teachers in their views about NOS, a professional development experience using explicit reflective instruction on NOS in the US. The Views of Nature of Science Questionnaire-Form B [VNOS-B] (Lederman, Abd-	Morrison, Raab and Ingram (2009)	VNOS-B	20 teachers	a professional development experience using explicit reflective instruction on NOS	Pre-post tests	EN 5%:→ 10%, Δ5 pp)	TN 5%: → 35%, Δ30 pp)	OI 0%: → 15%, Δ15 pp)	IC 0%: → 50%, Δ50 pp)	TL 0%: → 5%, Δ5 pp)		SC 0%:→ 20%, Δ20 pp)

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El-Khalick, Bell, & Schwartz, 2002) was employed in order to assess participants' views on the targeted features of NOS at the beginning and at the end of the 2-week course. At the end of the course, teachers showed informed views of NOS in TN (pre-test 5%: post-test 35%, Δ30 pp); IC (pre-test 0%: post-test 50%, Δ50 pp); EN (pre-test 5%: post-test 10%, Δ5 pp); SC (pre-test, 0%: post-test 20%, Δ20 pp); TL (pre-test, 0%: post-test 5%, Δ5 pp) and OI (pre-test, 0%: post-test 15%, Δ15 pp).												
In a study with 9 undergraduate teaching assistants, Hanuscin, Akerson, and Phillipson-Mower (2006) examined NOS views of participants, and the impact of job-embedded professional development on their views in the US. Four modes of explicit-and-reflective interventions were used in this study. The 10-item Views of Nature of Science Questionnaire (VNOS-C), developed by Lederman, Abd-El-Khalick, Bell, and Schwartz (2002), was administered to the nine participants in pencil-and-paper format prior to, and upon completion of, the semester. The results indicated that participants developed informed views of NOS in TN (pre-test, 100%: post-test,100 % Δ 0pp), EN (pre-test, 100%: post-test, 100% Δ 0 pp), OI (pre-test, 22%: post-test, 67% Δ 45 pp), NM (pre-test, 33%: post-test, 56% Δ 23 pp), IC (pre-test, 78%: post-test, 100% Δ22 pp), TL (pre-test, 11%: post-test, 89% Δ 78 pp) and SC (pre-test, 78%: post-test, 100% Δ22 pp).	Hanuscin, Akerson, and Phillipson-Mower (2006)	VNOS-C	9 undergraduate teaching assistants	explicit-and-reflective interventions	Pre-post tests	EN 100→ 100% Δ 0 pp)	TN 100% → 100 % Δ 0 pp)	OI 22% → 67% Δ 45 pp)	IC 78% → 100% Δ22 pp)	TL 11% → 89% Δ 78 pp)	NM 33% → 56% Δ 23 pp)	SC (pre-test, 78%: post-test, 100% Δ22 pp)
Abd-El-Khalick (2005) examined the effect of a philosophy of science course (POS) on NOS using 56 undergraduate and graduate pre-service secondary science teachers in the US. Two groups of teachers participated in this study, the method course group and the POS course group, in which participants received explicit, reflective NOS instruction. The Views of Nature of Science Questionnaire —Form C coupled with individual interviews was used to assess participants' NOS views at the beginning and conclusion of the study. At the conclusion of the study, results have shown that all 10 participants in the POS group have shown more informed views than the method group in TL (10.7% method group vs 53.6% POS group Δ43 pp), TN (26.8 % method group vs 58.9% POS Δ32 pp), OI (28.6% method group vs 71.4% POS Δ43 pp), EN (10.7% method group vs 60.7% POS Δ50 pp), IC (30.4% method group vs 60.7% POS Δ30 pp), and SC (39.3% method group vs 60.7%	Abd-El-Khalick (2005)	VNOS-C	56 undergraduate and graduate pre-service secondary science teachers	philosophy of science course	explicit, reflective NOS instruction	EN 11%→ 61% Δ50pp	TN 27%→ 59% Δ32pp	OI 29%→ 71% Δ43pp	IC 30%→ 61% Δ30pp	TL 11%→ 55% Δ43pp		SC 39%→ 61% Δ21pp

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POS Δ21 pp).												
In an explicit, reflective instructional approach study with 28 undergraduate students in the US, Abd-El-Khalick and Akerson (2004) used the Views of Nature of Science Questionnaire-Form B (VNOS–B) in conjunction with individual interviews was used to assess participants' views prior to and at the conclusion of the study. Results found showed informed views in IC (pre-test, 18%: post-test, 86% Δ68 pp), TL (pre-test, 11%: post-test, 75% Δ64 pp), NM (pre-test, 14%: post-test,68 % Δ54 pp), TN (pre-test,11 %: post-test, 64% Δ53 pp), OI (pre-test,25%: post-test, 75% Δ50 pp), and EN (pre-test, 29%: post-test, 71% Δ42 pp).	Abd-El-Khalick and Akerson (2004)	VNOS–B	28 undergraduate students	explicit, reflective instructional approach	Pre-post tests	EN 29% → 71% Δ42 pp	TN 11 % → 64% Δ53 pp)	, OI 25% → 75% Δ50 pp)	IC 18% → 86% Δ68 pp)	TL 11% → 75% Δ64 pp)	NM 14% → 68 % Δ54 pp)	
In a study with 25 undergraduate and 25 graduate preservice elementary teachers, Akerson, Abd-El-Khalick, and Lederman (2000) assessed the influence of a reflective, explicit, activity-based approach to NOS instruction undertaken in the context of an elementary science methods course on preservice teachers' views of some aspects of NOS in the US. An open-ended NOS questionnaire previously used and validated by Abd-El-Khalick *et al.* (1998) and Bell, Lederman, and Abd-El-Khalick (1998) coupled with individual interviews was used to assess participants' NOS views before and at the conclusion of the course. Results indicated that participants showed relatively more informed views in TN (pre-test,8 %: post-test, 52% Δ44 pp), EN (pre-test, 4%: post-test, 32% Δ 28 pp), IC (pre-test,24 %: post-test,80% Δ56 pp), SM (pre-test, 0%: post-test, 0% Δ 0 pp), OI (pre-test,40 %: post-test, 80% Δ40 pp). Less substantial gains were evident in TL (pre-test, 40%: post-test, 48% Δ8 pp) and SC aspects of NOS.	Akerson, Abd-El-Khalick, and Lederman (2000)	Opend-ended questionnaire	25 undergraduate and 25 graduate preservice elementary teachers	reflective, explicit, activity-based approach	Pre-post tests	EN 4% → 32% Δ 28 pp)	TN 8 % → 52% Δ44 pp)	OI 40 % → 80% Δ40 pp).	IC 24 % → 80% Δ56 pp)	TL 40% → 48% Δ8 pp)	SM 0% → 0% Δ 0 pp)	
In a study with 33 pre-service teachers in the Middle East, Baraz (2012) investigated the effect of using metacognitive strategies embedded in explicit–reflective NOS instruction to improve NOS understanding of pre-service science teachers. Participants were divided into two groups namely comparison and intervention group. Explicit reflective NOS instruction was used in both groups, but metacognitive strategies additionally used in	Baraz (2012)	Metacognitive Awareness Inventor (Schraw & Dennison, 1994) and Views of Nature of Science	33 pre-service teachers	Explicit reflective NOS instruction	Pre-post	EN 17%→ 47% Δ30pp	TN 11%→ 33% Δ22pp	OI 22%→ 47% Δ25pp	IC 56%→ 67% Δ11pp	TL 50%→ 73% Δ23pp		SC 22%→ 33% Δ11pp

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intervention group. Metacognitive Awareness Inventor (Schraw & Dennison, 1994) and Views of Nature of Science Questionnaire (VNOS-C) (Lederman *et al.,* 2001) were used as a pre-test–post-test, at the beginning and at the end of the study, to assess participants' views of NOS. Results demonstrated that explicit reflective NOS instruction enhanced the development of understanding of NOS in both groups. However, results also showed that metacognitive strategies improved the metacognitive awareness of intervention group participants. The intervention group also showed informed views in EN (E47:C17 Δ30 pp), TN (E33:C11 Δ22 pp), OI (E47:C22 Δ25 pp), IC (E67:C56 Δ11 pp), TL (E73:C50 Δ23 pp), SC (E33:C22 Δ11 pp).		Questionnaire (VNOS-C) (Lederman *et al.,* 2001)										
Yalçinoğlu and Anagün (2012) investigated the development of elementary science teachers' understandings of NOS as they were taught with an explicit approach in a NOS course in Turkey. The participants' views of NOS were evaluated with Views of Nature of Science Questionnaire form C (VNOS-C) before and after the intervention. Results indicated that 29 pre-service elementary science teachers performed well in SC (pre-test, 5%: post-test, 24% Δ 19 pp), TN (pre-test, 8%: post-test, 24% Δ 16pp), OI (pre-test, 5%: post-test, 20% Δ 15 pp), IC (pre-test, 18%: post-test, 28% Δ 10 pp), and did not do well in TL (pre-test,0 %: post-test, 0% Δ 0 pp) by an explicit approach.	Yalçinoğlu and Anagün (2012)	VNOS-C	29 pre-service elementary science teachers	explicit approach in a NOS course	Pre/post		TN 8%: →, 24% Δ 16 pp)	OI 5%:→ 20% Δ 15 pp)	IC 18%:→ 28% Δ 10 pp)	TL 0 %: → 0% Δ 0 pp)		SC 5%:→ 24% Δ 19 pp)
In a study with 36 elementary, middle, and high school teachers, Donnelly and Argyle (2011) investigated the extent to which these teachers were willing to adopt new strategies and activities for teaching NOS in their classrooms in the US. The same teachers were completing a year-long physical science professional development that included NOS instruction. Teachers' views on NOS were assessed using the Views of Nature of Science (VNOS-B) questionnaire developed and validated for use with high school, pre-service, and in-service teachers (Lederman *et al.,* 2002) was used as a pre- and post-test to assess teachers' views on NOS at the beginning and at the end of the professional development course. At the end of the course teachers showed informed views in TN	Donnelly and Argyle (2011)	VNOS-B	36 elementary, middle, and high school teachers	a year-long physical science professional development that included NOS instruction	Pre/post		TN 69% → 74% Δ5 pp)		IC 87% : → 97% Δ10 pp)	TL 13%: → 61% Δ48 pp)		

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(pre-test, 69% : post-test, 74% Δ5 pp); TL (pre-test, 13%: post-test, 61% Δ48 pp); and IC (pre-test, 87% : post-test, 97% Δ10 pp).											
In a study with 50 undergraduate science students, Vhurumuku (2010) investigated the influence of a short explicit-reflective Nature of Science Course on students' ideas about NOS at the University of the Western Cape in South Africa. Participants in this study completed both the pre- and post-intervention questionnaire containing questions which were selected and adapted from the Views of Nature of Science (VNOS) -Form C (Lederman *et al.*, 2002, p. 509). Results showed that participants performed better in TN (pre-test, 0%: post-test 84% Δ84 pp); difference and relationship between TL especially informed view that theories will never change into laws (pre-test, 0%: post-test 32% Δ32 pp), EN (pre-test,0%: post-test,16% Δ16 pp) and role of experiments in science in particular there are many ways including experimentation to generate scientific knowledge or NM (pre-test,6%: post-test,42% Δ36 pp).	Vhurumuku (2010)	VNOS) -Form C	50 undergraduate science students	explicit-reflective Nature of Science Course	Pre-post tests	EN 0%: →,16% Δ16 pp)	TN 0%:→ 84% Δ84 pp)			TL 0%: → 32% Δ32 pp)	NM 6%: →,42% Δ36 pp)

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Literature review C: studies that have either experimental and control groups, with some kind of intervention and where either VNOS questionnaires were used at the end of intervention.

Summary	Reference	Instrument	Subjects	Intervention	Type	Effect of intervention EN +6	TN +16	OI +4	IC +15	TL +14	NM +9	SC +9	OV
The present study	Baloyi (2014)	VNOS-C	1st year BSc students, doing practicals with ER NOS questions	ERGI laboratory practical activities	Post, exp-control	C: 64% E: 70% Δ6 pp	C: 32% E: 48% Δ16 pp	C: 38% E: 42% Δ4 pp	C: 18% E: 33% Δ15 pp	C: 8% E:22% Δ14pp	C: 10% E: 19% Δ9 pp	C: 8% E: 17% Δ9 pp	
Çıbık, (2016) compared the change of (3rd grade undergraduate students) pre-service science teachers' views about the nature of scientific knowledge through Project-Based History and NOS training and Conventional Method at an education faculty in Turkey. The sample in this study consisted of two groups: experimental and control. Student Understanding of Science and Scientific Inquiry questionnaire was applied to both groups as pre-test and post-test. The results showed that the experimental group performed better than the control group in five aspects of NOS: OI (pre-test 7%: post-test 22%, Δ15 pp), TN (pre-test 6%: post-test 21% Δ15%), TL (pre-test 7 %: post-test 21%, Δ14 pp), SC (pre-test 5%: post-test 23%, Δ18%), IC (pre-test 6 %: post-test 20%, Δ14 pp), and NM (pre-test 3.4%: post-test 24 %, Δ21 pp). Conversely the control group did better than the experimental group in TL and SC.	Çıbık, (2016)	Student Understanding of Science and Scientific Inquiry questionnaire	3rd grade undergraduate students/ pre-service science teachers	Project-Based History and NOS training and Conventional Method	Pre-post test, experimental and control		TN 6% →21% Δ15 pp)	OI 7% →22%, Δ15 pp).	IC 6 % →20%, Δ14 pp)	TL 7 % →21%, Δ14 pp)	NM 3.4% →24 %, Δ21 pp)	SC 5% →23%, Δ18 pp)	
In a study performed on 17 eleventh grade students in public high school in Ankara, Turkey, Nur and Fitnat (2015) examined the effects of NOS instruction with interactive historical vignette on students' views NOS and student development. The Views on the Nature of Science Questionnaire-form-C (VNOS-C) was used to evaluate participants' views of NOS before and after instruction. Results showed that the explicit-reflective approach to teaching of the chemical equilibrium unit enhanced students' understanding as reflected by the VNOS test. After the course, the	Nur and Fitnat (2015)	(VNOS-C)	17 eleventh grade students	explicit-reflective approach to teaching of the chemical equilibrium	Pre/Post	EN 55%: → 78% Δ23 pp	TN 45%: → 78% Δ 33 pp	OI 41%:→ 63% Δ22 pp	IC 67%: → 90% Δ23 pp	TL 29%:→ 49% Δ20 pp		SC 39%:→ 69% Δ30 pp	

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percentage of students with informed views was TN (pre-test, 45%: post-test, 78% Δ 33 pp), SC (pre-test, 39%: post-test, 69% Δ30 pp), IC (pre-test, 67%: post-test, 90% Δ23 pp each) , EN (pre-test, 55%: post-test, 78% Δ23 pp each), OI (pre-test, 41%: post-test, 63% Δ22 pp), and TL (pre-test, 29%: post-test, 49% Δ20 pp).											
In a study with 36 prospective science teachers, Celik and Bayrakceken (2012) investigated the effect of an activity based explicit NOS instruction undertaken in the context of a "Science, Technology and Society" course on the prospective science teachers' (PSTs') understandings of NOS in a Turkish college. Views on the Nature of Science Questionnaires (VNOS-B, C) (Abd-ElKhalick & Lederman, 2000b) were used to develop a modified questionnaire to assess PSTs conceptions at the beginning and at the end of the course. Findings indicated that participants performed well in TN (pre-test 3%: post-test 75%, Δ72 pp), TL (pre-test 0%: post-test 58%, Δ58 pp), OI (pre-test 36%: post-test 85%, Δ49 pp), through activity-based explicit approach. Participants did not do well in SC (pre-test 15%: post-test 40%, Δ25 pp), and IC (pre-test 12%: post-test 29%, Δ17 pp).	Celik and Bayrakceken (2012)	VNOS-B, C	36 prospective science teachers	explicit NOS instruction	Pre/post	TN 3%: → 75%, Δ72 pp	OI 36%: → 85%, Δ49 pp	IC 12%:→ 29%, Δ17 pp)	TL 0%:→ 58%, Δ58 pp)		SC 15%:→ 40%, Δ25%)
Sharif and Hasan (2012) used 76 tenth-grade students in Dubai to investigate students' views of NOS. These researchers further explored the impact of guided-inquiry of instruction in teaching the environmental biology subject and NOS aspects with students. Participants in this study were assigned to experimental and control groups. The experimental group was taught using the guided inquiry instruction during theoretical classes and laboratory activities. The control group was taught using the traditional strategies, without incorporating the guided inquiry instruction and the science process-skills. Students' NOS views were assessed using a NOS scale (NOSS) questionnaire using questions extracted from the articles; Wenning (2006) and Iqbal *et al.* (2009), and the doctorate thesis for Larson-Miller (2011). Differences in the total average scores between pre- and post-NOS tests showed that the experimental group performed better than the control group in NM (pre-test 72%: post-test 86%, Δ14 pp) and TL (pre-test 72%: post-test 72% Δ0 pp).	Sharif and Hasan (2012)	NOS scale (NOSS) questionnaire	76 tenth-grade students	guided-inquiry of instruction in teaching the environmental biology subject and NOS aspects	pre- and post-NOS tests, control vs experimental groups				TL 72% →72% Δ, 0 pp)	in NM 72% →86%, Δ14 pp)	
Yalçinoğlu and Anagün (2012) investigated the	Yalçinoğlu	VNOS-C	29 pre-service	explicit	Pre/post	TN 8%:	OI	IC	TL 0 %:		SC

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development of elementary science teachers' understandings of NOS as they were taught with an explicit approach in a NOS course in Turkey. The participants' views of NOS were evaluated with Views of Nature of Science Questionnaire form C (VNOS-C) before and after the intervention. Results indicated that 29 pre-service elementary science teachers performed well in SC (pre-test, 5%: post-test, 24% Δ 19 pp), TN (pre-test, 8%: post-test, 24% Δ 16pp), OI (pre-test, 5%: post-test, 20% Δ 15 pp), IC (pre-test, 18%: post-test, 28% Δ 10 pp), and did not do well in TL (pre-test,0 %: post-test, 0% Δ 0 pp) by an explicit approach.	and Anagün (2012)		elementary science teachers	approach in a NOS course			→, 24% Δ 16 pp)	5%:→ 20% Δ 15 pp)	18%:→ 28% Δ 10 pp)	→ 0% Δ 0 pp)		5%:→ 24% Δ 19 pp)
In a study with 36 elementary, middle, and high school teachers, Donnelly and Argyle (2011) investigated the extent to which these teachers were willing to adopt new strategies and activities for teaching NOS in their classrooms in the US. The same teachers were completing a year-long physical science professional development that included NOS instruction. Teachers' views on NOS were assessed using the Views of Nature of Science (VNOS-B) questionnaire developed and validated for use with high school, pre-service, and in-service teachers (Lederman *et al.,* 2002) was used as a pre- and post-test to assess teachers' views on NOS at the beginning and at the end of the professional development course. At the end of the course teachers showed informed views in TN (pre-test, 69% : post-test, 74% Δ5 pp); TL (pre-test, 13%: post-test, 61% Δ48 pp); and IC (pre-test, 87% : post-test, 97% Δ10 pp).	Donnelly and Argyle (2011)	VNOS-B	36 elementary, middle, and high school teachers	a year-long physical science professional development that included NOS instruction	Pre/post		TN 69% → 74% Δ5 pp)		IC 87% : → 97% Δ10 pp)	TL 13%: → 61% Δ48 pp)		
Kim and Irving (2010) explores the effectiveness of the contextualized history of science on student learning of NOS and genetics content knowledge (GCK) in high school biology classrooms in the US and provides an exemplar for teachers on how to utilize history of science in genetics instruction; and suggests a modified concept mapping assessment tool for both NOS and GCK. A quasi-experimental control group research design was utilized with pretests, post-tests, and delayed post-tests. The participants were 31 10th-grade high school Biology students that were also assigned to experimental group (16 students) and a control group (17 students). Participants' views of NOS were assessed using several methods including NOS Terms Definition with Concept Mapping, the View of Nature of Science-Form C (VNOS-C) developed by AbdEl-Khalick in 1998 and semi-structured interviews. The results indicated that	Kim and Irving.(2010)	VNOS-C	31 10th-grade high school Biology students	contextualized history of science on student learning of NOS	Pre- post tests, control vs experimental groups	EN 0% →23%, Δ23 pp),	TN 0% →2%, Δ2 pp)	OI 0% →11%, Δ11 pp)	IC 0% →16%, Δ16 pp)	TL 6% →16%, Δ10 pp)		SC 5%→18 %, Δ13 pp)

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students in the experimental group developed better understanding of NOS after the intervention in EN (C0%:E23%, Δ23 pp),TN (C0%:E2%, Δ2 pp),IC (C0%:E16%, Δ16 pp), SC (C5%:E18%, Δ13 pp),OI (C0%:E11%, Δ11 pp) and TL (C6%:E16%,Δ10 pp).												
In a study with 50 undergraduate science students, Vhurumuku (2010) investigated the influence of a short explicit-reflective Nature of Science Course on students' ideas about NOS at the University of the Western Cape in South Africa. Participants in this study completed both the pre- and post-intervention questionnaire containing questions which were selected and adapted from the Views of Nature of Science (VNOS) -Form C (Lederman *et al.*, 2002, p. 509). Results showed that participants performed better in TN (pre-test, 0%: post-test 84% Δ84 pp); difference and relationship between TL especially informed view that theories will never change into laws (pre-test, 0%: post-test 32% Δ32 pp), EN (pre-test,0%: post-test,16% Δ16 pp) and role of experiments in science in particular there are many ways including experimentation to generate scientific knowledge or NM (pre-test,6%: post-test,42% Δ36 pp).	Vhurumuku (2010)	VNOS) -Form C	50 undergraduate science students	explicit-reflective Nature of Science Course	Pre-post tests	EN 0%: →,16% Δ16 pp)	TN 0%:→ 84% Δ84 pp)			TL 0%: → 32% Δ32 pp)	NM 6%: →,42% Δ36 pp)	
Yacoubian and BouJaoude (2010) investigated the effect of reflective discussions following inquiry-based laboratory activities on 38 grade six Lebanese students' views of NOS. The study used a pre–post test control-group design and focused on collecting mainly qualitative data. During each laboratory session, students worked in groups of two. Later, experimental group students answered open-ended questions about NOS then engaged in reflective discussions about NOS. Control group students answered open-ended questions about the content of the laboratory activities then participated in discussions of results of these activities. Results indicated that explicit and reflective discussions following inquiry-based laboratory activities enhanced students' views of the target NOS aspects: TN (E 0%: C 5%, Δ -5 pp), EN (E 45%: C 6%, Δ39 pp), and SC (E 30%: C-6%, Δ36 pp) more than implicit inquiry-based instruction.	Yacoubian and BouJaoude (2010)	open-ended questions about NOS	38 grade six Lebanese students	reflective discussions following inquiry-based laboratory activities	pre–post test control vs experimental groups	EN 6% →45%, Δ39 pp)	TN 5%→0 %, Δ -5 pp)					SC 6% →30%Δ 36 pp)
Abd-El-Khalick and Akerson (2009) investigated the influence of training in, and use of, metacognitive strategies on the development of 49 prospective elementary teachers' views of NOS in the US. Participants were randomly assigned to an	Abd-El-Khalick and Akerson (2009)	VNOS-C	49 prospective elementary teachers	explicit-reflective NOS	Pre-post test, intervention group vs	EN 46% →68%, Δ22 pp),	TN 50% →72%, Δ22 pp)	OI 41% →64%, Δ23 pp)	IC 55% →56 %, Δ1 pp)			

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intervention group and a comparison group. The participants' conceptions of the target aspects of NOS and their metacognitive awareness were assessed using the VNOS-C (Lederman *et al.*, 2002). Students in both groups were engaged with explicit-reflective NOS instruction in two sections of an elementary science methods course, which focused on the EN, TN, OI and IC NOS aspects. Results indicated that significantly more students in the intervention group expressed more informed views of EN (pre-test 46%; post-test 68%, Δ22 pp), TN (pre-test 50%; post-test 72%, Δ22 pp), OI (pre-test 41%; post-test 64%, Δ23 pp)and IC(pre-test 55%; post-test 56 %, Δ1 pp).					comparison group							
In a study with three teachers and their students, 89 ninth-graders and 40 10th/11th-graders in the US, Khishfe and Lederman (2007), investigated the relationship between instructional context (integrated and non-integrated) that explicitly teaches about NOS and students' view of NOS across different disciplines (Environmental groups, and Chemistry groups). Participants in the study were divided into two groups, integrated or non-integrated . The treatment for all groups involved teaching a 5–6 week unit that included the science content and NOS. The two intact groups learned about same content; the only difference was the context of NOS instruction (integrated or non-integrated). An open-ended questionnaire VNOS-C in conjunction with individual interviews was used to assess participants' NOS views. The results in this study show that students in the Environmental group (Integrated) versus Environmental group (Non-integrated) for example showed informed views in TN (pre-test 24% : post-test 42%, Δ18 pp), EN (pre-test 47% : post-test 62%, Δ15 pp), OI (pre-test 52% : post-test 71%, Δ19 pp), and IC (pre-test 30% : post-test 57%, Δ27 pp).	Khishfe and Lederman (2007)	VNOS-C	89 ninth-graders and 40 10th/11th-graders	explicitly teaching about NOS	Pre-post test, integrated vs non-integrated groups	EN 47% →62%, Δ15 pp)	TN 24% →42%, Δ18 pp)	OI 52% →71%, Δ19 pp)	IC 30% →57%, Δ 17pp)			
In a study with 9 undergraduate teaching assistants, Hanuscin, Akerson, and Phillipson-Mower (2006) examined NOS views of participants, and the impact of job-embedded professional development on their views in the US. Four modes of explicit-and-reflective interventions were used in this study. The 10-item Views of Nature of Science Questionnaire (VNOS-C), developed by Lederman, Abd-El-Khalick, Bell, and Schwartz (2002), was administered to the nine participants in pencil-and-paper format prior to, and upon completion of, the	Hanuscin, Akerson, and Phillipson-Mower (2006)	VNOS-C	9 undergraduate teaching assistants	explicit-and-reflective interventions	Pre-post tests	EN 100→ 100% Δ 0 pp)	TN 100% → 100 % Δ 0 pp)	OI 22% → 67% Δ 45 pp)	IC 78% → 100% Δ22 pp)	TL 11% → 89% Δ 78 pp)	NM 33% → 56% Δ 23 pp)	SC (pre-test, 78%: post-test, 100% Δ22 pp)

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semester. The results indicated that participants developed informed views of NOS in TN (pre-test, 100%: post-test,100 % Δ 0pp), EN (pre-test, 100%: post-test, 100% Δ 0 pp), OI (pre-test, 22%: post-test, 67% Δ 45 pp), NM (pre-test, 33%: post-test, 56% Δ 23 pp), IC (pre-test, 78%: post-test, 100% Δ22 pp), TL (pre-test, 11%: post-test, 89% Δ 78 pp) and SC (pre-test, 78%: post-test, 100% Δ22 pp).												
In a study with 42 ninth grade students in Chicago, US, Khishfe and Lederman (2006) investigated the influence of two different explicit instructional approaches on participants' views on NOS. An open-ended questionnaire, with four questionnaire items were taken and slightly modified from the Nature of Science Survey used by Khishfe and Abd-El-Khalick (2002) in conjunction with semi-structured interviews was used to assess students' views before and after instruction. There were 42 students who participated in this study and were assigned to two groups: the ''integrated'' group and the ''non-integrated'' group. For the ''integrated'' group, NOS instruction was related to the science content about global warming. For the ''non-integrated'' group, NOS was taught through a set of activities that specifically addressed NOS issues and were dispersed across the content about global warming. The treatment for both groups lasted 6 weeks and addressed a unit about global warming and NOS. The results indicated that students showed informed views in TN (Non-integrated group 24%: Integrated group 42%, Δ18 pp), EN (Non-integrated group 47% : Integrated group 62%, Δ15 pp), OI (Non-integrated group 52% : Integrated group71%, Δ19 pp) and IC (Non-integrated group 43% : Integrated group 57%, Δ14 pp).	Khishfe and Lederman (2006)	Nature of Science Survey	42 ninth grade students	explicit instructional approaches	Pre-post test, integrated vs non-integrated groups	EN 47% →62%, Δ15 pp	TN 24% →42%, Δ18 pp	OI 52% →71%, Δ19 pp	IC 43% →57%, Δ14 pp)			
Abd-El-Khalick (2005) examined the effect of a philosophy of science course (POS) on NOS using 56 undergraduate and graduate pre-service secondary science teachers in the US. Two groups of teachers participated in this study, the method course group and the POS course group, in which participants received explicit, reflective NOS instruction. The Views of Nature of Science Questionnaire —Form C coupled with individual interviews was used to assess participants' NOS views at the beginning and conclusion of the study. At the conclusion of the study, results have shown that all 10 participants in the POS group have shown more informed views than the method group in TL (10.7% method group vs 53.6% POS group	Abd-El-Khalick (2005)	VNOS-C	56 undergraduate and graduate pre-service secondary science teachers	philosophy of science course (POS) on NOS	Pre-post test, method course group and the POS course group	EN 10.7% →60.7 % Δ50 pp)	TN 26.8 % →58.9 % Δ32 pp	OI 28.6% →71.4 % Δ43 pp	IC 30.4% →60.7% Δ30 pp	TL 10.7% →53.6 % Δ43 pp		SC 39.3% →60.7 % Δ21 pp

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Δ43 pp), TN (26.8 % method group vs 58.9% POS Δ32 pp), OI (28.6% method group vs 71.4% POS Δ43 pp), EN (10.7% method group vs 60.7% POS Δ50 pp), IC (30.4% method group vs 60.7% POS Δ30 pp), and SC (39.3% method group vs 60.7% POS Δ21 pp).									
Khishfe and Abd-El-Khalick (2002) investigated the influence of an explicit and reflective approach and inquiry-oriented approach to teaching science on 62 sixth-grade students in Beirut, Lebanon. Themes for the questionnaire used in the present study were adoptedfrom a VNOS-C questionnaire used by Abd-El-Khalick (1998). The participants were assigned to the intervention or explicit group and the comparison or implicit group. The intervention or explicit group was engaged in inquiry activities followed by reflective discussions of the target NOS aspects. The comparison or implicit group was engaged in the same inquiry activities. However, these latter activities included no explicit references to or discussion of any NOS aspects. The results showed that the intervention group showed more informed views in TN (Implicit group 0%: Explicit group +46%, Δ46 pp), EN (: Implicit group +3%: Explicit group +42%, Δ39 pp), OI (Implicit group +11%: Explicit group +31%, Δ20 pp) and IC (Implicit group-3%: Explicit group 31%, Δ34 pp) than the implicit group.	Khishfe and Abd-El-Khalick (2002)	VNOS-C	62 sixth-grade students	explicit and reflective approach and inquiry-oriented approach	Pre-post tests, intervention or explicit group and the comparison or implicit group	EN +3% →+42%, Δ39 pp)	TN 0% →+46%, Δ46 pp)	OI +11% →+31%, Δ20 pp)	IC 3% →31%, Δ34 pp)

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