An investigation of the development of inquiry skills in Biology students through collaborative work

Valentina Aquilina

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ABSTRACT

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An investigation of the development of inquiry skills in Biology students through collaborative work

This qualitative case study, explored the development of inquiry skills in Biology students, the students’ ability to apply these skills was then observed whilst they were carrying out inquiry based laboratory investigations. These tasks were completed in collaborative groups. The aims of this research were: (i) to investigate whether fifteen year old Biology students would be able to apply learnt problem solving inquiry skills to a problem solving task whilst still learning topic content; and (ii) to explore to what extent fifteen year old Biology students work collaboratively when dealing with inquiry tasks.

The participants of this study were a class of ten Form 5 male Biology students. The data were collected during the 2013-2014 scholastic year. The inquiry skills lessons took place over three weeks, and the actual implementation of the IBL lessons through the topic of ‘Soil and Agriculture’ took place over another three weeks. The main data sources included teacher observation (which included field notes taken on site and later elaborated into reflections), focus group sessions with the collaborative groups, individual interviews, students’ work written whilst working in groups and individually, an end of topic test and an inquiry task six months after the investigations.

The research findings indicate that inquiry skills lessons benefitted most students as they could apply them to an inquiry task both within a collaborative group and individually. Six months later, most students remembered the inquiry skills and were able to apply them to the task given. Students of all abilities experienced success through an IBL pedagogy. Apart from gaining inquiry skills the students also succeeded in collaborating with their peers. From my observations I could conclude that collaboration was only achieved when each student contributed to the group and felt that they were respected and accepted within their group.

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INQUIRY, IBL, INQUIRY SKILLS, COLLABORATIVE WORK, BIOLOGY, SECONDARY SCHOOL, CASE STUDY
Statement of Authenticity

I declare that this study has been carried out by the author and no part of it has been published or presented elsewhere.

________________
Valentina Aquilina
Dedication

To my husband to be, Andrew,
my parents Elizabeth and Oscar,
my brother Andre’ and my close friends
thank you for always offering your love
and support, I could not have done this
without you.
Acknowledgements

I would like to express my gratitude to all who in one way or another were part of this research.

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Valentina Aquilina

January, 2015
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Chapter 1

Introduction
1.0 Introduction

This study examined the use of Problem Based Inquiry Learning through collaborative work in the teaching of Biology to a group of students in a church school. Recent shifts in Maltese curricula, which were preceded by the Vision for Science Education consultation document (MEEF, 2011a), have encouraged a pedagogical shift in the way science is being taught. This shift being from a more traditional approach to teaching science, to an approach which is more inquiry based.

The aim of this study was to explore whether students can be taught specific inquiry skills and whether they can apply these skills to everyday problems in the topic of “Soil and Agriculture.” A secondary focus of this study was to explore whether the participants would succeed in working within a collaborative group in order to solve the inquiry problems given to them. The new curricula have also encouraged the teaching of science to be done through collaborative learning. The Vision for Science Education (MEEF, 2011a) makes reference to Lave & Wenger (1991), to describe how recent educational studies claim that “students learn best when they engage with each other and learn from one another.” This is also described as a “community of practice” (p. 35).

1.1. Rationale of the study

When I was asked to decide on a topic for my Masters dissertation, the only thing I wanted to do was something practical and which took place in the classroom. A research area which would help, not only me as a teacher and researcher but more importantly would also be beneficial to my students and to other teachers.

Problem solving inquiry tasks in the science classroom have always been of interest to me as a teacher of Biology. Prior to the study I had only used problem solving inquiry
tasks rarely and only because they were an obligatory part of the Secondary Education Certificate (SEC) practical work component. I decided to take my interest a step further by researching the subject in greater depth. According to Boeiji (2009), it is important to find “a research topic that is of interest to you and will engage you” (p. 2) and for this reason I chose to pursue this topic for my research. I chose to teach a topic called ‘Soil and Agriculture’ using inquiry based learning (IBL). From my previous years teaching this topic, students normally considered it to be ‘boring’ and monotonous as a topic and I wanted to see whether IBL would change the way my students felt and responded to the topic.

From my prior experiences with problem solving activities, I had also realised that to carry out these tasks students need specific inquiry skills which they were never taught explicitly but were just expected to have picked up from their science lessons throughout the years. In my study I opted to carry out a set of lessons which dealt with specific inquiry skills before teaching the topic of “Soil and Agriculture”. Following the inquiry skills lessons the students had to carry out problem based inquiry tasks in collaborative groups and individually. These tasks were used to understand whether students were able to apply previously taught skills to the problem or not. The final research interest in my study was to investigate whether students would succeed in solving problems within a collaborative group or not and to what extent they were able to collaborate.

1.2. Context of the study

The Maltese education system is composed of three types of schools; these are the state, church and independent schools. According to the Ministry of Education, Employment and the Family (MEEF) (2011b), compulsory schooling in Malta consists of three cycles; these are the early years (kindergarten), primary years (Year 1 to Year 6) secondary years (Form 1 to Form 5). Following compulsory schooling students could then choose to further their education in a tertiary education institution. The
school in this study was within the Church school sector, this will be described in the next section.

1.2.1. The Church School sector

The Secretariat for Catholic Education is in charge of Church schools in Malta. According to the National Statistics Office (NSO) (2010), 32% of the total student population attend a primary or secondary church school. Currently entrance into Church schools is through a ballot system which leads to a mixed ability student population. Since many schools contain both a primary and a secondary section, students normally transition easily from primary schooling to secondary schooling. Church schools are single sex schools, the school in this study being a boys’ school.

1.3. The research questions and strategies used to answer these questions.

The research questions for this study were:

1. Will fifteen year old Biology students be able to apply learnt problem solving skills to a problem solving task, whilst still learning topic content?
2. To what extent do fifteen year old Biology students work collaboratively when dealing with inquiry tasks?

In order to answer these questions I chose to carry out a case study. Answers to the research questions were obtained through my observations of students during the inquiry and problem based tasks. The students’ planning sheets of the laboratory based tasks were analysed to understand whether the students could apply the previously learnt skills to the problems or not. Following the tasks, the student groups
who were working collaboratively took part in a focus group which served to give me an insight in the group dynamics. The students then attended an individual interview where students were asked about the tasks carried out in the collaborative groups.

During the individual interview the students were also given an individual task whose aim was to understand their ability to complete a task on their own. Data were also gathered through an end of topic test to comprehend whether learning and understanding of the topic content still took place although a different pedagogy was used. The students were also given a task six months after the inquiry skills lessons to understand whether long-term learning of the skills took place or not.

1.4. The dissertation

The dissertation is made up of six chapters.

Chapter 1 served to introduce the study and what inspired me as a researcher to pursue this research question. The Maltese education system was also described in order to place this study within its context. Attention was also given to recent local policy documents which recommended a shift from traditional teaching towards an inquiry based pedagogy.

Chapter 2 reviews the literature giving particular importance to: inquiry based learning (IBL) and its history, problem based learning (PBL), their place in modern science teaching, the theoretical underpinnings of IBL, criticisms of IBL, inquiry in the classroom, challenges experienced by teachers, a discussion of local teacher research, assessment in the inquiry classroom and collaborative learning.

Chapter 3 describes the research methodology. The chapter focuses on: the setting of the study, the ethical considerations which were taken, the research questions, the
research strategy and the research tools used to answer the research questions, validity and reliability, the tasks used in this study and how the data were analysed.

**Chapter 4** presents and discusses the research findings related to the first research question and whether the students were able to apply the previously learnt inquiry skills to a problem within a group and individually. This chapter also focused on whether students would be able to learn topic content through inquiry.

**Chapter 5** presents and discusses the research findings related to the second research question and whether the students succeeded in working collaboratively with their peers.

**Chapter 6** concludes the research and discusses my experience of using IBL, summarizes the main findings of the study, the strengths and limitations of the research, possibilities for future research and implications for practice.
Chapter 2

Literature review
2.0. Introduction

The Maltese science education community has recently been emphasizing the need to teach science through the process of inquiry or through inquiry based learning (IBL). The recent consultation document, a ‘Vision for Science Education in Malta’ (MEEF, 2011a), has supported the need for a change in the way science is being taught in local schools. Other agencies related to science education and the scientific community, also support the need for a change in the way science is taught in Malta. Examples include the University of Malta that participated in the PRIMAS project (Promoting inquiry-based learning (IBL) in mathematics and science across Europe) introducing inquiry in Maltese secondary schools over the years 2010-2013. The Maltese Association of Science Educators (MASE), also supports the need for a change in the way science is taught in Malta, and in fact organised a number of seminars which promote this new way of teaching both in primary and secondary settings.

In the Vision for Science Education in Malta, (MEEF, 2011a) there was a proposed need for change in the way that science education is perceived, a ‘paradigm shift’, promoting “inquiry-based learning that requires a deeper and integrated understanding of science and how scientific knowledge is structured” (p.14). The main differences between IBL and the traditional approach is an increased emphasis on the “processes of science rather than solely on content knowledge.” (p. 37). The finalised National Curriculum Framework (NCF) (MEEF, 2012) does not give a lot of detail with regards to inquiry based learning (IBL) and collaborative work; however it does list learning outcomes that cannot be achieved through the transmission of knowledge.

Apart from the recent changes in the curriculum, the science syllabi as outlined by the Matriculation and Secondary Education Certificate Examination Board (MATSEC) have long encouraged the use of inquiry based activities in the Biology, Chemistry and Physics classrooms through problem solving investigations. These problem solving investigations as envisaged by MATSEC involve inquiry in the science classroom. With regards to Biology, problem solving investigations are an obligatory part of the MATSEC syllabus (2014a). Students are asked to present “at least three” (p.17)
problem solving investigations, therefore at least one-fifth of laboratory work submitted, needs to be of this nature.

This chapter will review the literature on IBL and collaborative learning within a Science classroom, particularly a Biology classroom. These are the main areas which concern my study, the main focus being on whether students will experience meaningful learning through an IBL pedagogy and by working collaboratively.

2.1. Inquiry based learning

2.1.1. What is inquiry based learning (IBL)?

Inquiry based learning can be described as a method of learning science, which according to the National Research Council (NRC), resembles the way science is actually done by scientists (2000). Students work in a way which mirrors the way that scientists work, therefore students come up with their own questions, formulate hypotheses, and design a method which they can use to test these hypotheses and then answer the question which they had asked at the beginning of the investigation. There are many existent definitions of IBL, yet for the purpose of this study; the definition of IBL which is most fitting is that of Linn, Davis and Bell. This definition has been adopted by many leading reports, studies and projects such as the Rocard et al. (2007) and PRIMAS (2011b). PRIMAS (2011b) cites Linn Davis and Bell’s definition of IBL as being “the intentional process of diagnosing problems, critiquing experiments, and distinguishing alternatives, planning investigations, researching conjectures, searching for information, constructing models, debating with peers and forming coherent arguments” (p.7).
2.1.2. How do ‘real’ scientists work?

According to Koch (2000), ‘the scientific process’ is composed of a group of skills and techniques which are used when carrying out an experiment. These skills can be referred to as ‘science process skills’, and can be said to be ‘transferable’ and can be used in other facets of daily life which are not directly related to science.

Through IBL, students have opportunities to learn and practice these science process skills. According to Alberts (2000), “Along with science knowledge, we want students to acquire some of the reasoning and procedural skills of scientists, as well as a clear understanding of the nature of science as a distinct type of human endeavour” (p. 4). Walker (2007), cited The American Association for the Advancement of Science (1993), which put together two different lists of process skills, these lists being ‘basic process skills’ and ‘integrated process skills.’

The science process skills are skills which are needed in order to do a scientific investigation. The basic skills are as follows:

- Observation
- Classifying
- Measuring
- Communication
- Inferring
- Predicting (Walker, 2007, p. 21)

The Integrated Science Process Skills include:

- Controlling variables: being able to first recognize the variables related to the experiment and then be able to regulate all the variables except the one which is being manipulated in the experiment.
- Defining operationally: this skill is needed to identify which measurements need to be recorded in the results and the frequency of taking measurements.
Formulating hypotheses: The skill of being able to make a prediction about what could happen as a result of the experiment and to also give a scientific explanation for why this will occur.

Collecting data: the way a researcher collects information in an organized manner.

Interpretation of data: The way data from the experiment are firstly organized, analysed and then interpreted.

Experimenting: the designing of a method which will be used in order to test the hypothesis.

Making models: The use of information to be able to simulate a particular scientific event or observation. (Walker, 2007, p. 22)

The integrated skills described above are more complex and require more practice than the basic skills. In fact the ‘basic skills’ are meant to be mastered by students in primary school level and the ‘integrated skills’ should be learnt as the students get older. According to Walker (2007), nowadays it is very important that students learn how to do science and not just learn the concepts and facts about science.

2.1.3. Modern students’ learning needs and styles

Friesen and Jardine (2009), quote students who discuss how they wish they were taught. Some of these quotes were: “We don’t want to remember, recall and regurgitate”; “We want to do work that is relevant, meaningful and authentic” and “We don’t want learning made easy” the authors then add “rather, they want it to mean something”(p.3).

According to Dunkhase (2002) gone are the days when science instruction was based on students just regurgitating content knowledge, formulae and definitions, since this did not promote meaningful learning and students did not learn or understand the science concepts they studied. For this reason the people who studied science could
not apply what they learnt in class to their everyday lives, therefore studying science did not improve their scientific literacy. Lord and Orkwiszewski (2006) claimed that students nowadays are “no longer content to sit passively through a lecture or laboratory activity, rather today’s students need to be engulfed in it” (p. 242). They also claim that students need to be mentally involved in lessons and not just physically involved.

Inquiry will promote meaningful learning in science, since according to Dunkhase (2002) the focus is on “content knowledge in the context of the process of developing scientific understanding.” (p.11). Therefore it is a way of learning scientific concepts by the students actually doing science and constructing these concepts for themselves with the help and guidance of a teacher. Therefore we can conclude that inquiry has become important as science pedagogy because it caters for modern students who are not satisfied with the traditional way of teaching and it also leads to more meaningful learning.

2.1.4. The difference between an inquiry based classroom and a traditional classroom

If one had to look at a traditional science classroom and at an IBL classroom, they would be different in a number of ways. According to Walker (2007), having a ‘hands-on’ activity does not mean that the activity is inquiry based. In a traditional classroom, the teacher would explain the important science concepts which need to be learnt and the students would then be given a recipe-type hand-out which contains step by step instructions on how to carry out the experiment related to the topic. Students would then conduct the experiment which was intended to reinforce the science concept which they have just learnt. Everything related to the experiment would then be written in the form of a laboratory report at the end of the lesson. This does not reflect the way real scientists carry out laboratory research. Research is typically conducted in order
to solve a problem, whilst when students are given all the information needed prior to an experiment; it just serves to reinforce already known facts.

Walker claims that a lesson which is inquiry based is very different to a traditional lesson; the teacher normally starts off the lesson by either showing students an interesting science phenomenon or by showing them a video, presenting them with a problem related to the topic or by using a demonstration. When the students are more advanced and used to inquiry learning, the teacher could even guide them to coming up with their own problem or question which could then be investigated. After finding a problem which needs to be ‘solved’, students may go about formulating a hypothesis and a method which they can then use to solve the problem which was presented to them. IBL can also be referred to as an inductive approach to learning since students are not given all the facts and knowledge prior to investigating a problem; students arrive at a law or are able to generalize upon their observations or the results of their experiments. In this way students are conducting research in a way similar to how real scientists work.

2.1.5. Inquiry based learning as an ‘inductive’ approach to education

Rocard, Csermely, Jorde, Lenzen, Walberg-Henriksson, & Hemme, (2007) and Spronken-Smith (2012) claim that inquiry-based learning can be considered an ‘inductive’ approach to education, an approach which contrasts greatly with the more traditional ‘deductive’ approach to education.

Prince and Felder (2007) describe the deductive approach to teaching as when “the instructor first teaches students relevant theory and mathematical models, then moves on to textbook exercises, and eventually – maybe- gets to real-world applications” (p. 14). They also claim that through this method students find it hard to connect what is being learnt in class with real-life situations and for this reason many students leave
the sciences. For this reason there is a need to motivate students, which according to Prince and Felder (2007) can be done through inductive pedagogies.

Prince and Felder (2007) claim that different pedagogies can be said to be inductive in nature such as: discovery learning, inquiry-based learning, problem-based learning, project based learning, case-based teaching and just-in-time teaching. This study will be focusing on two of these: inquiry-based learning and problem-based learning.

An inductive approach to education has been defined by Prince and Felder (2007) and Spronken-Smith (2012), as a pedagogy in which the process of learning begins with the educator presenting their students with either a complex real-life problem or a number of observations and information which needs to be interpreted. Then it is up to the teacher to guide them on how to proceed or to help them to learn independently.

Spronken-Smith (2012) outlines key characteristics of inductive approaches to education. The first characteristic is that it is student or learner centred; the focus of learning is on the student and the teacher is not there just to transmit knowledge or solutions to problems. The second characteristic is that learning is “active” and this means that the students “learn by doing”, this can be achieved by students working together through discussion of situations, questions and problems. The third characteristic is the acquisition of “self-directed learning skills” (p. 2); through this method of learning students become more responsible for their own learning. The fourth characteristic is the constructive theoretical basis which suggests that students create their own meaning of reality. For this reason what is taught by transmission methods do not directly translate into what the students learn. The last characteristic is that learning normally occurs through collaborative or cooperative learning, where students work in groups and learn together.

The following section will describe problem based learning (PBL), which is a form of IBL.
2.2. Problem based learning (PBL)

One form of inquiry based learning is problem based learning. The definition of PBL which will be used in this study is that found in the Rocard Report (2007) which defined PBL as “a learning environment where problems drive the learning” (p.10). Spronken-Smith (2012), defined the relationship between IBL and PBL; she claimed that PBL tends to involve “complex, ill-structured open-ended real world problems, while IBL may possibly use such problems” (p. 4). Another difference according to Spronken-Smith, Angelo, Matthews, O’Steen, and Robertson (2007), is that PBL always involves collaborative work between students and IBL can be done in this way. Spronken-Smith et al., also claim that PBL takes place over a short period of time while IBL can take place over a longer period of time.

Barrett (2005) explains that PBL tasks are not “teacher’s exercises” (p.56), they are “messy not tidy, incomplete in the sense of lacking information and iterative in the way that they produce further ideas/ hypotheses and learning issues” (p. 56). Barrett also emphasized the need for problems to be appealing to students in the sense that they feel real and are, both stimulating and thought-provoking to students.

If students are engaged by the activity this will provoke them to learn about the subject and to research it and to think about solutions and ways to present their work. Since many of these activities can be done in groups, students can work together in a way which is similar to how they would work together in their future jobs and careers. Learning would occur in such a way that students would need to obtain new information in order to find a solution to the problem. Yet instead of looking for just one correct answer, students understand the problem, find related information, think of solutions, think of their options and then reach a conclusion. Unfortunately according to Burgh, Haynes, Gillies, and Nichols (2012), very often students do not get to experience this situation since they are more often than not, passive recipients in the learning process.

Greenwald (2000) claims that in a traditional classroom setting, students are only given problems to solve after they have been given all the information required to solve
the problem. This gives students the false impression that problems only arise in a situation where all the needed information to solve the problem is already available. Barrett (2005) metaphorically describes the situation as being “like making a cake when you have already been given the recipe and all the ingredients” (p. 56).

An important aspect of problem based learning is that the problems are given at the beginning of a unit hence it is referred to as a “problem-first” approach. This helps students to conceptualize why they are learning what is being done in class. Gallagher, Stepień, Sher, and Workman (1995), emphasise that the order of learning in PBL is representative of everyday problems and problem solving, where solutions to a problem are not normally available.

Lee and Ward (2002), claimed that the education system needs to change because employers are looking for employees who have “excellent communication skills, the ability to work collaboratively to solve problems, an understanding of statistics, and the ability to creatively solve ill-defined problems” (p. 17). For this reason students cannot remain passive quiet recipients in the classroom. The introduction of problem-based learning would solve this problem. This would prepare students both for life and the work place. Mauffette, Kandlbinder and Soucisse (2004) claim that through PBL, “students take greater responsibility for their own learning, with the benefit that they develop a wider range of transferable skills such as communication skills, teamwork and problem-solving.” (p. 11).

The main focus of PBL is on the students and the process is shaped and initiated by them. This teaching method according to Pepper (2009) and Hmelo-Silver, Golan Duncan and Chinn (2007), encourages deeper learning. According to Greenwald (2000), students learn science best when they “experience problems which challenge science” (p. 1). Learning occurs through the thought process they experience whilst trying to find a solution to these problems. Even though students’ curiosity should be considered to be a ‘natural resource’ in the classroom, very few students ask questions which are related to their own interest. Through PBL, students have an opportunity to investigate in depth what should be learnt through their science lessons and also things which may peak their curiosity.
After exploring different facets of inquiry and problem based learning, one cannot help wonder about the history of this pedagogy.

2.3. Historical background of IBL

Although inquiry based learning has become increasingly popular in recent years, it is not a new phenomenon. According to Pine, Aschbacher, Roth, Jones, McPhee, Martin, Phelps, Kyle Foley (2006), scientific research through inquiry started in the 17th century when Galileo “rolled balls down ramps” (p. 468). Since then scientists have used inquiry in order to answer questions about the natural world. Even though advances in scientific inquiry started early, the idea that science education should be done through student investigations took a while to pick up and gain support.

Table 2.1 identifies a few of the major historical milestones in the development of inquiry based learning.

Table 2.1: Major historical milestones in the development of inquiry based learning

<table>
<thead>
<tr>
<th>Date</th>
<th>Event/ Developments in IBL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mid 1800s</td>
<td>‘Science’ as a school subject was only introduced as part of the main curriculum in many countries in the mid-19th century and science was taught through rote learning (Pine et al. 2006).</td>
</tr>
<tr>
<td>Year</td>
<td>Event</td>
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</table>
| 1902 | Dewey described as the forefather of inquiry, started reflecting on a need to change the curriculum to one which is more inquiry based. Dewey (1902) claimed:  
“The logically formulated material of a science is no substitute for the having of individual experiences. The mathematical formula for a falling body does not take the place of personal contact and immediate individual experience with the falling thing” (p. 20). |
| 1910 | Barrow (2006) claimed that Dewey recommended the introduction of inquiry in 1910; he felt that there was too much emphasis on facts without enough emphasis on science through thinking. |
| 1916 | Dewey encouraged a teaching strategy which resembled the scientific method but was very specific and made up of six steps: “sensing perplexing situations, clarifying the problem, formulating a tentative hypothesis, testing the hypothesis, revising with rigorous tests, and acting on the solution” (Barrow, 2006, p.266). |
| 1927 | Dewey’s scientific method model set the foundations for the Commission on Secondary School Curriculum’s document ‘Science and the Curriculum’ in 1927 (Barrow, 2006). |
| 1950s | In the 1950s, the works of Schwab, Dewey, Bruner and Piaget on child development influenced the nature of curriculum materials (Pine et al., 2006). |
| 1957 | The Russian Sputnik became the first successful spacecraft. As a result science education became high priority for the National Science Foundation (NSF) and high school science projects were not only encouraged but they were even funded. Inquiry became a fundamental part of the science curricula. (Pine et al., 2006). |
| 1960 | According to Nixon and François (2007) the 1960s also brought with them major revision of science education in the US, through changes to the science curricula which greater emphasized inquiry approaches.  
Schwab (1960) claimed that the science laboratory should “cease to be a place where statements already learned are merely illustrated and where perception of phenomena occurs within the restrictive structuring of terms and concepts already laid down” (p.187). Therefore the science experiments should not just be used to illustrate already known facts but should be used in order to ‘discover’ science through inquiry. |
<table>
<thead>
<tr>
<th>Year</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1961</td>
<td>The psychologist Bruner (1961) who encouraged discovery learning claimed that “… one encounters repeatedly an expression of faith in the powerful effects that come from permitting the student to put things together for himself, to be his own discoverer” (p. 21).</td>
</tr>
<tr>
<td>1970s</td>
<td>According to Nixon and François (2007), in the 1970s, science educators in the US started to question the ‘extreme’ versions of discovery science which encouraged minimal teacher intervention. The 1970s also gave rise to educational philosophers who introduced the concept of constructivism. The emphasis of constructivism being on how to achieve meaningful learning rather than focusing on rote learning</td>
</tr>
<tr>
<td>1980s</td>
<td>Science educators started to think about how ‘authentic inquiry’ (p.2) can be done in the science classroom (Nixon and François, 2007).</td>
</tr>
<tr>
<td>2000</td>
<td>Nixon and François, claim that the new millennium brought with it more focus on ‘scientific inquiry’ rather than on ‘scientific processes’. More importance was given to ‘evidence, explanation and current scientific knowledge’ (p.2).</td>
</tr>
<tr>
<td>2007</td>
<td>In the Rocard Report, Rocard et al. (2007), encouraged school science to be taught through a more student centred pedagogy and to shift towards an inquiry based teaching approach since it would improve attitudes and could eventually encourage more students to choose science.</td>
</tr>
</tbody>
</table>

As can be seen from its history, inquiry has been around for a long time especially in the scientific community. Changes in society have shaped the way inquiry learning has changed throughout the years.
2.4. Theoretical underpinnings of IBL

2.4.1. Constructivism

Inquiry based learning draws on the philosophy of constructivism. Constructivism is a philosophy of learning which is explained by Cobern (1993) as “learning is not knowledge written on, or transplanted to, a person's mind as if the mind were a blank slate waiting to be written on or an empty gallery waiting to be filled” (p.51). The name of the theory itself metaphorically resembles the ideas it represents: where knowledge is constructed or built by an individual and only that individual is capable of changing pre-constructed knowledge. According to Ausubel (1968) “if I had to reduce all of educational psychology to just a single principle, I would say this: “find out what the learner already knows and teach him accordingly” (p. 337). Therefore in order to help students to understand and to learn, the teacher first needs to understand what their students’ prior knowledge is and move on from there.

Cobern (1993) claimed that although constructivism has its roots in Piaget's theories of education, the late 1970s brought the rise of the constructivist learning theory through the influential works of Ausubel, Novak and Driver & Easley. Later on in the 1980s, it was the work of von Glasersfeld which caused a shift towards radical constructivism.

Taber (2011) claims that the modern form of constructivism; “has as its basis how people make sense of their experience” (p.40). Schooling is not as simple as the teacher passing on their knowledge to their students. Students have a mental framework within which they need to fit and make sense of the new information being taught; this leads to meaningful learning. Taber explains, “Each learner develops personal knowledge that is a unique reconstruction of the teacher’s knowledge by interpreting the public representation of the teacher’s knowledge through available interpretive resources” (p.44).
Another thing which needs to be considered is the mental framework which students have prior to learning. This prior framework can easily contain misconceptions which will limit their current learning. According to Hodson (1998), it is the teacher’s task to help students to alter their framework in order to accommodate the new information being discussed in class. Posner, Strike, Hewson and Gertzog (1982), claim that in order to deal with misconceptions or “alternative frameworks” (p.211), a student needs to first become discontented with their current framework and conceptions. When they realise their current framework is incorrect, they can then change their previous ideas in order to accommodate a new set of concepts which are seen to be “intelligible and rational” (p.212), this is called ‘conceptual change’ and is a theory attributed to Vygotsky.

According to Anderson (2007) and Walker (2007), the principal ideas in constructivism which are related to inquiry learning are:

- **Learning is a process which is active**, and students are able to construct their own meanings for themselves. Whilst learning, students are able to build up or construct new ideas and concepts, they do not just receive information. Students learn best when they do something and not just hear something. Learning by doing is described as ‘concrete hands-on learning,’ Walker (2007, p.33).

- **Prior knowledge**: Walker claims that students cannot be described as a *tabula rasa* since they already have ideas and knowledge from their previous experiences. They then base what they learn upon what they knew and experienced previously. Therefore any new meanings which an individual constructs are based upon their prior understanding. This prior knowledge can be said to be the ‘foundations’ upon which to build up and construct new knowledge. Learners may even come to the classroom with misconceptions and it is important that the teacher understands these misconceptions and then uses the learning process to change the incorrect ideas.

- **Knowledge is constructed**: learners are able to create and construct their own ideas and understanding. Therefore teachers do not simply pass on knowledge
to their students. The ideas which students build up for themselves are constructed upon their ‘foundations’ or their prior knowledge. If their new idea does not fit into the framework of their previous knowledge, ‘cognitive conflict’ occurs and the learner must change what they previously learnt in order to include the new information, (Walker, 2007).

✓ **Learning is dependent on the environmental setting:** What an individual understands and learns is dependent on the setting within which that learning took place. The setting of a learner is both the physical environment and even the social environment. According to Anderson (2007), learning is “socially constructed; understanding is enriched by engagement of ideas in concert with other people” (p. 809). According to Taber (2011), these ideas where further enhanced through Vygotsky’s socio-cultural perspective, “where the personal concepts of individuals are modified by interactions with others, to allow the development of a somewhat common language, and to some extent at least a sharing of concepts” (p.50). Vygotsky’s socio-cultural theory is discussed in section 2.8., which deals with collaborative work.

Although there are many favourable characteristics of constructivist approaches to education such as PBL and IBL which have been identified and discussed, there are also critics who pose unfavourable arguments against them.
2.5. What are the arguments against discovery learning, PBL and IBL?

Although IBL and PBL are pedagogies which have recently been given a lot of importance since they are currently ‘in vogue’ or ‘on trend’ within the science education community, there are many critics who go against these philosophies of teaching. Critics often group discovery learning, PBL and IBL together and do not distinguish between these pedagogies which are similar because they are student centred but at the same time they are very different from each other because of the way they bring about learning.

Since these terms are often confused it is important to make each term explicit in its meaning. IBL has been defined in section 2.1.1., and problem based learning has been defined in section 2.2. yet discovery learning still needs to be defined. According to Alfieri, Brooks, Aldrich, & Tenenbaum (2011), discovery learning can be defined as an occasion where “the target information must be discovered by the learner within the confines of the task and its material” (p.2). They further explain this definition by claiming that “discovery learning occurs whenever the learner is not provided with the target information or conceptual understanding and must find it independently and with only the provided materials” (p.2). The level of support and assistance given to the students by the teacher directly affects the difficulty experienced by the students in order to discover the information which was targeted by the teacher. Therefore if the teacher does not help students to discover what they should be learning, this is referred to as pure or unguided discovery and if the teacher helps their students then this is referred to as guided or structured discovery. Mayer (2004) who reviewed literature on discovery learning claimed that in each case he studied, “guided discovery has been more effective than pure discovery in helping students learn and transfer” (p. 14).

The following are some of the criticisms which have been brought against IBL, PBL and discovery learning. The research of Barrett (2005), cited the work of Norman and Schmidt (1992) who compared traditional approaches to teaching with PBL in a medical school setting. Their results showed that a deeper form of learning resulted
from PBL units and students also found it easier to apply their knowledge to clinical situations. Yet when their results were compared to those of students who were taught in a more traditional way, the students who experienced traditional methods of education obtained higher marks on their knowledge of sciences when compared to the students who experienced problem-based learning methods. One may say that if students were asked to sit for an exam which was meant to test lower order skills, then rote learning would give better results. For this reason the type of assessment also needs to change to assess the wider range of skills learnt when taught through PBL.

According to Barrett (2005), a challenge which might arise when trying to use inquiry and problem based learning, is that it would be difficult to convert to this method of learning when the staff and students in a school are used to more traditional pedagogies. Trying to change a whole school or university to a PBL pedagogy would be difficult since a short staff development programme about the new pedagogy would not be enough to change a philosophy of teaching overnight. Jarvis et al. as cited by Barrett (2005), claimed that these approaches to teaching and learning would need a change in the curriculum, not just within schools but within all educational institutions. There would be a need to move away from the idea of ‘disciplines’ toward the idea of inter-disciplinary or multi-disciplinary staff groups. These are big changes which take a lot of time and need structures like committees or working groups, who can work towards bringing about this change.

Another argument brought against PBL, IBL, and discovery learning, was made by Kirschner, Sweller & Clark (2006). They claimed that these pedagogies ignore research which has been done on ‘cognitive overload’, where the learners’ working memory is overwhelmed, this being particularly so if the learner is a beginner. Bryant and Tech (2011), countered Kirschner et al.’s argument by saying that PBL can actually reduce students’ cognitive overload. They claim that:

“When students are given an appropriate amount of guidance, are provided with a question that informs them of what they are expected to accomplish, and when debate and discussion is used to scaffold students’ understanding, cognitive load may be reduced” (p. 165).

Kirschner et al. (2006) also claimed that these methods of teaching require much more time than traditional techniques since students have to construct their own knowledge on their own. In Malta, as in other countries, this is an important challenge
being faced by teachers since at the end of secondary school, students face local high stakes examinations which examine extensive syllabi. Therefore limited time available to cover material for the syllabi can deter teachers from using PBL or IBL pedagogies. Anderson (2002) also mentioned this dilemma he claimed teachers experience “an overriding commitment to ‘coverage’ because of a perceived need to prepare students for the next level of schooling” (p.8).

Although Kirschner et al. (2006) formed a strong argument against discovery learning, PBL and IBL, their understanding of these pedagogies were different from those used in this study and numerous other sources. Kirschner et al. placed discovery learning, inquiry and problem based learning together and defined them as ‘pure discovery’. Pure discovery was defined as “unguided, problem-based instruction” (p.79), they also refer to these pedagogies as being ‘minimally guided instruction’ which can be defined as “learners, rather than being presented with essential information, must discover or construct essential information for themselves” (p. 1). In response to Kirschner et al., (2006), Hmelo-Silver et al. (2007) claim that this is a distortion of what actually makes up both problem and inquiry based learning. In reality both forms of learning need a lot of scaffolding and guidance from the teacher, they claim that “scaffolding makes the learning more tractable for students by changing complex and difficult tasks in ways that make these tasks accessible, manageable, and within students’ zone of proximal development” (p. 100). This implies that the teacher’s understanding of inquiry is important as it may influence the type and amount of scaffolding they provide in their practice.

The following section will discuss the different levels and approaches to inquiry which practitioners may take when adopting an inquiry or problem based approach to teaching.
2.6. Inquiry and practice

2.6.1. The different levels of inquiry

The level of inquiry of an activity chosen by a teacher increases in intensity the more teachers surrender their control with regards to a number of pedagogical features (such as questioning, planning and analysing data) in order to give students more ownership of their own learning. In the literature there are various classifications to describe the level of inquiry a teacher adopts. The classifications which helped me the most were those of Tafoya, Sunal and Knecht (1980) which is a simple classification system which is very easy to understand and that of Fradd, Lee, Sutman & Saxton (2001) which is a more detailed classification system.

In their classification system, Tafoya et al. (1980), claimed that inquiry is divided into structured, guided, open inquiry and confirmation exercise. ‘Open inquiry’ can be described as a lesson which is solely inquiry based, therefore it is the students who choose the problem and questions to investigate and also the method they will use in order to answer the questions they are investigating.

According to the National Research Council (1996), ‘open inquiry’ can be described as an approach which is student-centred; it starts off with questions posed by the students, then the students (who can work in groups) design and carry out investigations or research which will lead them to results which can then be presented. Through this method of inquiry, students experience learning science in a way which is similar to the way scientists actually work. Martin-Hansen (2002), claims that this form of inquiry promotes “higher-order thinking and usually has students working directly with the concepts and materials, equipment, and so forth” (p. 25). Through this method, students are able to ask questions which will guide them towards solving a particular problem using materials provided by the teacher. The data collected through their investigation will then be used to display and explain results to the rest of the class.
According to Colburn (2000), ‘guided inquiry’, is different from ‘open inquiry’ since the teacher plays a more prominent role in the investigation. The teacher is usually the one who decides the questions or investigation which the students then need to explore or investigate. They then work in groups to decide on how they should proceed with the investigation. Banchi and Bell (2008) claim that in this form of inquiry the teacher is not passive, but “students need guidance as to whether their investigation plans make sense” (p. 27). After carrying out the investigation, the students discuss their findings with the rest of the class.

Windschitl and Buttemer (2000), define ‘structure inquiry’ as when “teachers typically constrain students’ experiences by furnishing questions and the procedures for resolving those questions, with the intent of having all students converge on a single acceptable outcome” (p. 346). According to Martin-Hansen (2002), the only thing which is not provided by the teacher is the expected outcome. It is a more traditional approach to inquiry because students are following instructions given by the teacher to reach a specific target. The drawback to this approach is that “student engagement in the lessons is limited to following teacher instructions” (p. 27). For this reason structured inquiry does not really include ‘true inquiry’ since it is the teacher who is making the choices. Students learn more when they are given the opportunity to think about the choices they make in the science classroom. Similar to structured inquiry is the ‘confirmation exercise’, which is not really an inquiry based activity since the teacher gives the students the solution to the question at the beginning of the lesson, the teacher then gives instructions on how to conduct the experiment to confirm the results. This practice is very common in many traditional science class rooms.

Fradd et al. (2001), created an inquiry matrix which suggests that instead of just classifying inquiry as being ‘open’ or ‘structured inquiry’, inquiry may be regarded as something which occurs over a continuum. Table 2.2, on the following page refers to Fradd et al.’s inquiry matrix which shows the different levels of inquiry.
Fradd et al. (2001) described how a lesson can be classified through the inquiry matrix. A lesson can be broken down according to the criteria used in the matrix (from questioning to applying) in order to show whether the decisions were made by the teacher or the student. From their observations Fradd et al., concluded that some areas of inquiry could more readily be done by students for example conducting experiments and reporting results. Other activities such as questioning and applying findings to scientific concepts required more experience.

Through the matrix the ‘openness’ of a lesson can be determined according to how often students and teachers are given the opportunity to make decisions. Using this table allows teachers to uncover how ‘open’ their lesson which may encourage more inquiry. It can also guide teachers in ways of increasing the inquiry level over time.

The following section will discuss the difficulties experienced by teachers in the inquiry classroom.

<table>
<thead>
<tr>
<th>Inquiry Level</th>
<th>Questioning</th>
<th>Planning</th>
<th>Implementing</th>
<th>Concluding</th>
<th>Reporting</th>
<th>Applying</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Carrying out plan</td>
<td>Analyse Data</td>
<td>Draw conclusions</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>Teacher</td>
<td>Teacher</td>
<td>Teacher</td>
<td>Teacher</td>
<td>Teacher</td>
<td>Teacher</td>
</tr>
<tr>
<td>1</td>
<td>Teacher</td>
<td>Teacher</td>
<td>Students/Teacher</td>
<td>Teacher</td>
<td>Teacher</td>
<td>Students</td>
</tr>
<tr>
<td>2</td>
<td>Teacher</td>
<td>Teacher</td>
<td>Students</td>
<td>Students/Teacher</td>
<td>Students/Teacher</td>
<td>Students</td>
</tr>
<tr>
<td>3</td>
<td>Teacher</td>
<td>Students/Teacher</td>
<td>Students</td>
<td>Students</td>
<td>Students</td>
<td>Students</td>
</tr>
<tr>
<td>4</td>
<td>Students/Teacher</td>
<td>Students</td>
<td>Students</td>
<td>Students</td>
<td>Students</td>
<td>Students</td>
</tr>
<tr>
<td>5</td>
<td>Students</td>
<td>Students</td>
<td>Students</td>
<td>Students</td>
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<td>Students</td>
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</tbody>
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The following section will discuss the difficulties experienced by teachers in the inquiry classroom.
2.6.2. Challenges teachers face when teaching in an inquiry classroom.

According to Walker (2007), the first thing a teacher needs to consider when thinking of using inquiry activities in the class is the actual topic which he/she wishes to portray using this teaching style. This could be done in another way, by first having a topic or lesson and then thinking of ways of how it could be taught through an IBL pedagogy. Walker (2007) claims that not all topics are suitable for inquiry pedagogy, therefore it is important to choose a topic which is not abstract but concrete. The choice of topic or experiment which can be taught through inquiry is the first challenge a teacher experiences.

For Walker (2007), the inquiry classroom is very different from the more traditional setting. In a lecture style lesson the teacher is more in control of the class and is able to observe every student, the teacher is also the one who does more of the talking and students sit passively and only talk when they are supposed to answer a question. In this setting students do not really interact with each other. In an inquiry based lesson, class management becomes much more of a challenge. Students are given a certain amount of freedom in order to decide how they wish to go about a particular task. The teacher does not stand at the front of the class and observe the students but instead goes around the class in order to help and offer support. Inquiry-based teaching also highlights the use of collaborative learning where students discuss ideas and work with peers in order to carry out a particular task. All the conditions which set the stage for an inquiry based lesson may encourage students to interact with their peers and to do other things apart from what they should be doing for their task; these students can easily escape the teacher who is busy moving around the class helping their classmates.

According to Lawson (2000), the major challenges which a teacher faces when using inquiry-based lessons are the following:

- Students who do not participate in inquiry activities
- Students who are unsure about how to go about inquiry activities; for example students do not know how to start the activity or lack the information which they
need in order to start. Students may also not wish to think for themselves and expect to be spoon-fed by the teacher.

- Students who may not wish to carry out an inquiry based project
- Students who talk to their peers at the wrong time and do not listen to the teachers’ instructions
- Students may become disruptive, bored or inattentive
- Students who use lesson time to socialise with their peers instead of work on tasks.
- Students cheat or plagiarize other students work.

These challenges may be experienced in any lesson but even more in an inquiry lesson since students are given more freedom. Walker (2007) gives suggestions on how to overcome challenging behaviour experienced in an inquiry lesson. He suggests that students are grouped in small mixed ability groups where each student has a role or task which needs to be carried out. By doing so there is less chance of students becoming passive, disruptive, or unsure about how to work on a particular task.

The following section will discuss ways of improving student motivation.

2.6.3. How to increase student motivation

According to Hmelo-Silver (2004), an advantage to student centred learning (such as IBL and PBL) is that many students become intrinsically motivated as they are interested in what they are studying. Unfortunately according to Walker (2007), some students may feel lost when carrying out an inquiry task since this pedagogy may be new to them. For this reason it is important for the teacher to start off using tasks which give students a more structured approach to the inquiry task.

The difficulty level of the task should be suitable and not too difficult for the students. According to Colburn (2000) inquiry activities should be “just right” (p. 42). Students
could become demotivated if the activity is too hard and as a result will not be able to complete it, whilst if the activity is too easy students will not be challenged and become bored and restless. Very often inquiry tasks challenge students more than other forms of teaching and for this reason it is important for the teacher to remain strong and not give in when students are too lazy to think for themselves. Inquiry teaching helps students to become more independent and this will be very important for their future lives.

The following section will discuss various forms of research related to the local teachers’ perspectives of IBL conducted by researchers in Maltese schools.

2.6.4. Local teachers’ perspectives and research on implementing inquiry based learning

Dalli (2004), focused on teachers’ perspectives on Biology investigations and also came up with guidelines which would encourage the successful implementation of investigative practical work for teachers. Dalli’s research took place after the introduction of problem-solving investigations by MATSEC. These problem solving investigations are intended to be taught through IBL pedagogy since students are given a problem about which they have to conduct an investigation.

From her interviews with Biology teachers, certain patterns arose. For example the teachers in her study felt that “students should have vast knowledge of the topics and have to be familiar with different apparatus, in order to be able to think of possible investigations” (p.52). Time management was another problem which was brought up by the teachers in the study who felt that investigations “take longer than usual practicals and are not worth the time” (p.52). Lack of clear guidelines was another problem mentioned; in fact one teacher claimed that “the idea of investigative practicals is still not very clear. There should be more guidance for teachers” (p.53).
The teachers in Dalli’s study claimed that through investigations students became more mature and investigations helped them to think in a more intellectual manner. Students also “have to develop their own techniques, solve problems, learn to think critically and find flaws in their own methods” (p.54). The investigations also encouraged students not to cheat when writing experimental data results as they sometimes would in recipe type experiments. In recipe type experiments the students’ predictions and expected data would be based on theories which were already covered in class and students would alter their experimental results to match those which they were expecting because of prior knowledge.

Students’ ability to effectively write down experiment procedures was also discussed by Micallef (2010). Micallef, whose study focused on whether students (who successfully completed their SEC Physics examination and who have chosen to further their studies in the subject) have acquired the inquiry skills which are proposed by the SEC physics syllabus or not. Micallef chose particular inquiry skills (graph interpretation and experimental design) and then tested the students’ abilities in these skills by assessing them through questions in a questionnaire.

Micallef (2010), claimed that students found difficulties in most of the skills assessed through the questionnaire. A notable difficulty was when students had to write an experimental procedure in the experimental design question. Some students were unable to describe a suitable method and others did not write a method which complemented their diagram. When the Physics Education officer (EO) was asked to comment on this finding he said “unfortunately most of our students are still being given ready-made procedures for which they have to change the sentence structure or the fill-in type of practical procedures were students have to fill in simple words” (p.81). This comment illustrates the fact that very often teachers do not carry out investigations which are problem solving in nature. Teachers tend to only carry out ‘recipe-type’ experiments which do not encourage the students to think of their own methods as they are given all the information by the teacher. The teachers who were interviewed by Micallef said that they feel that students would benefit more from investigations where the students were central to the thinking process yet they felt restricted by time, an issue which was also brought up in Dalli’s (2004) research.
The study of Sultana, Vassallo and Vella (2011) focused on Chemistry investigations in Malta. Their main aim was to understand the perspectives of both teachers and students with regards to chemistry investigations. Most of the teachers participating in the study felt that investigations are beneficial to their students. Investigations helped to improve students’ thinking skills and their motivation towards the subject. Teachers felt that the overall enjoyment of the subject improved through investigations since students like working within a group. An interesting point reported in this research was that the teachers who participated in the study viewed investigations in different ways; some left the students to work completely on their own whereas others still gave a lot of guidance.

According to Sultana, Vassallo and Vella (2011), many teachers felt that through investigations students could learn from their own mistakes, especially when they plan the wrong method to test their hypothesis. They learn from their mistakes because it was they who came up with the method to begin with. Yet overall the teachers in the study did not think that students actually gained a better understanding of the scientific method or subject content through investigations.

Unlike the results obtained by Dalli (2004), most of the teachers participating in Sultana, Vassallo and Vella’s study appreciated the benefits of investigations. A possible reason for this change in attitude towards investigations is the change in trends in science education and the changes which took place in the curriculum which favoured an inquiry based pedagogy.

Muscat (2010) focused on teachers’ perceptions of Physics investigations. Physics investigations are not currently a compulsory part of the coursework for the SEC examinations. Muscat found that although investigations were not compulsory, at least half the teachers who participated in her study did conduct investigations. A good proportion of teachers even felt that investigations should become a compulsory part of the coursework. Most of the teachers who participated in her study felt that investigations are beneficial to their students. The greatest difficulty which deterred teachers from conducting investigations was classroom control. The teachers who did not conduct any investigations claimed this was because they felt investigations are too difficult for their students.
Grech (2010), changed the way she taught Physics in order to incorporate a more inquiry based approach to the subject. She felt that teaching was a much more rewarding experience because of the enthusiasm and success of her students. Grech introduced IBL through activities which were more guided and later on increased the openness of the activities. Although it was challenging for her to adapt to this new way of teaching, she felt that it was not only the students who benefitted from this approach but she was “utterly enjoying these lessons as well” (p.117). Through an IBL pedagogy she managed to increase student motivation, make the subject more relatable to everyday life, tackle misconceptions and achieve a better student-teacher relationship. The only difficulty she mentioned was the time constraints when using this pedagogy. Grech claimed:

“I also felt restricted to the kind of activities I was able to carry out with my student. This is because I had to finish the syllabus on time, and there was a lot to do in a short period of time” (p.126).

Grech’s problem with time management whilst incorporating IBL in her lessons echoes the concerns of the teachers in Dalli’s (2004) and Micallef’s (2010) studies. Grech also discussed the issue of lack of classroom management which was pointed out by teachers in Muscat’s (2010) study. Grech claimed that “students would be louder during inquiry and it increases the appearance of disorder in the classroom” (p.139), especially when compared to a traditional classroom. Despite this, Grech never felt that she lost control of the classroom.

Camenzuli (2012), experienced first-hand how IBL can be used in order to help students with socio-emotional behavioural difficulties (SEBD), his findings discussed below, easily contradict those of the teachers involved in Muscat’s study. Camenzuli, conducted a study which focused on whether IBL could be used to help students with SEBD to understand a mathematics unit. Through his study Camenzuli experienced first-hand the positive effect of IBL since not only did his students understand the mathematics content better but they also behaved better because of the design of the lessons. For example students who found it hard to sit down and listen were helped because through the IBL process they could get up and move around the class to discuss with their peers. Therefore through IBL, students who had SEBD were able to over-come their weaknesses and this allowed them to enjoy the learning process. In fact, Camenzuli (2012) claims that “students’ on-going written and verbal comments
revealed how they thoroughly enjoyed learning through IBL and how this ‘new way of learning’ worked far better for them than the transmission model.” (p. 88). Through Camenzuli’s study we can conclude that IBL activities need to be adapted according to students’ needs, they can even be used with students who have learning or behavioural difficulties. If used correctly, IBL activities can serve to improve student understanding, motivation and behaviour in the classroom, these results complement those obtained by Grech (2010).

When thinking about the practical uses of inquiry in the classroom, it is also important to reflect on the methods of assessment which will not only assess content knowledge but also the skills students learn through this pedagogy. In this study it was important for me to think of how to assess whether the students acquired the inquiry skills and still learnt content knowledge through IBL. Assessment will be discussed in the next section.

2.7. Assessment in the inquiry classroom

2.7.1. Assessment and IBL

In every learning situation, it is important to think about how students will be assessed. Walker (2007) stressed the importance of assessment, since strict objectives are set by curricula and examination boards because students need to be prepared to sit for important examinations. On the other hand Barrell (2007) claimed that we need to move away from the ‘high-stakes testing’ (p.152), especially in the classroom. Assessment is useful since it gives the teacher insight into what the students know or do not know. Unfortunately through these tests we can never be sure about what students are actually learning.

Barrell (2007) differentiates between a ‘test’ and an ‘assessment’, the former being “a short-term means of gathering discrete information that has limited validity in terms of
helping teachers form judgments about the depth and quality of students’ understanding of the complex issues, ideas, concepts, skills and dispositions that are the core of PBL” (p.152). On the other hand an ‘assessment’ is a more personal approach which is designed in order for both the teacher and the students to understand the level of learning a student has achieved. This is especially relevant when teaching using IBL and PBL; it is very important that the teacher knows what students have understood and what skills they have acquired; not just what they memorized.

Although various methods of assessment exist, more often than not, teachers tend to teach towards a particular examination. Very often these examinations, examine a vast syllabus and teachers feel pressured to cover all the content or syllabus which students require to pass the exam. If the exam were to include inquiry skills and higher order skills then more teachers would presumably teach through inquiry. Therefore if the curriculum is encouraging science teachers to adopt a more inquiry based pedagogy, there also needs to be a shift in the way students are assessed to include these new skills.

Traditional means of assessment like examinations are a barrier to the IBL classroom. According to Macdonald (2005), assessment in the IBL and PBL classroom should represent how students are able to apply the “knowledge and skills to increasingly complex situations, involving a range of intellectual and practical activities in a variety of contexts” (p.86). Assessment tasks should provide situations in which students could find themselves in the future, for example providing a particular situation which could be experienced by a nurse, geologist or a physicist, this would show whether students are capable of applying what they learnt to the situation at hand.

Both Walker (2007) and Barrell (2007) encourage the use of more modern and creative ways of assessing students. Their suggestions include asking students to make a poster on a topic, planning sheets especially when it comes to planning an investigation, or even brainstorming at the beginning and the end of a particular topic to understand what students learnt; perhaps through a concept map.

According to Barrell (2007), when assessing science skills, various techniques can be used such as assessment rubrics which identify specific criteria and explain exactly
what students have achieved. Another technique is the use of a checklist to determine whether students have learnt a particular skill or not. Should the teacher need to include a test in their assessment, this may be a short test which encourages students to apply what they have learnt to the question at hand.

2.7.2. Summative and formative assessment

A common way of classifying assessment is as either being ‘summative’ or ‘formative’. Walker (2007) describes ‘summative’ assessment as being assessment which occurs after learning has taken place, this is normally done through a test on a particular topic. This method of assessment is very common in the non-inquiry classroom. According to Harlen (2003), ‘formative’ assessment refers to the way that information is gathered about students’ learning throughout the “course of learning” (p. 9). In formative assessment, the teacher is responsible to collect “evidence of students’ skills, concepts, and attitudes relevant to the goals of learning” (p.9). The teacher could also include the students in their own assessment. Formative assessment could be carried out in order to understand whether students have achieved learning goals or not, it could then help the teacher to decide next step for them to achieve success. A key difference between formative assessment and summative assessment is that in formative assessment, the teacher continuously discusses student progress with the student and guides them to continue to improve.

According to Walker (2007), the teachers of an inquiry classroom do not just want to know if students have gained knowledge, they also want to know whether they have acquired science process skills and whether they have ‘built’ their understanding of a particular topic in the correct way. For this reason formative assessment is the foundations of what makes up an inquiry class. Teachers firstly need to understand what their students know before they start a new topic, they then build on their students’ prior knowledge or adapt accordingly. Formative assessment in the inquiry class is a continuous process according to Walker, this occurs “whenever you have a
class discussion, ask students questions or prompt students to think about their experiments” (p. 162). At the same time it is important to ensure that what is being done in class can be applied by students when they need to sit for summative assessment.

Black and William (1998), conducted an in-depth analysis of formative assessment, and found it has a very favourable effect on student learning and as a result of this positive effect, students achieve better results in summative testing. Through teacher feedback, students were capable of understanding their difficulties and the areas which needed to be improved. In fact they claimed that “formative assessment helps low achievers more than other students and so reduces the range of achievement while raising achievement overall” (p. 4).

2.7.3. Peer and self-assessment

Peer and self-assessment are two methods of formative assessment which have been recommended by the NCF (2012). The ideal method of assessment would be a combination of “assessment for learning”, and “assessment of learning” (p.41). Assessment should be used throughout the learning process and not just to sum up what has been learned when it is already too late to change. Self and peer-assessment are two methods of assessment which encourage learners to reflect upon their learning and increase self-improvement. According to MEEF (2011a) in the Vision for Science Education, “the principles of assessment for learning, including identifying learning outcomes, giving quality feedback, questioning and the use of self and peer assessment are more adapted to investigative science” (p. 20).

According to Andrade and Du (2007), self-assessment is “a process of formative assessment during which students reflect on and evaluate the quality of their work and their learning, judge the degree to which they reflect explicitly stated goals or criteria, identify strengths and weaknesses in their work, and revise accordingly” (p.160). They further simplify their definition by stating that “we see self-assessment as feedback for
oneself from oneself” (p.160). According to Spiller (2012), there are many advantages to self-assessment: it promotes responsibility and independence in learners; it also encourages students to look at learning as a process and it supports the shift from teacher-centred learning to student-centred learning.

According to Spiller (2012), peer-assessment “essentially involves students providing feedback to other students on the quality of their work”. Thomas, Martin & Pleasants (2011), also included the provision of feedback and grades to other students on “a product, process, or performance, based on the criteria of excellence for that product or event which students may have been involved in determining” (p. 3). According to Black and Wiliam (1998), very often teachers fear that students are unreliable and cannot be trusted with any form of assessment, yet normally students are “too hard on themselves” (p.7).

Black and Wiliam claim that the real problem encountered when students carry out self or peer-assessment is that students “can only assess themselves when they have a sufficiently clear picture of the targets that their learning is meant to attain” (p.8). Very often students are passive recipients of their learning and are not really sure of the goals and learning objectives related to what they are studying in class. Therefore if teachers choose to incorporate peer or self-assessment in their lessons, they need to ensure that their students know exactly what they are assessing and what counts as good work, which can be done by providing them with criteria for assessment. If self and peer-assessment is done properly assessment becomes a form of discussion with both the teacher and other students in the class, this helps students to improve their learning and reflect on it as a process. Since students are encouraged to reflect and think about their learning, it now becomes a very important form of formative assessment. In IBL, formative assessment takes place when students are encouraged to reflect on the procedures which they chose and when they evaluate the results obtained.

A key characteristic of an IBL classroom is the use of collaborative learning, which will be discussed in the next section.
2.8. Collaborative learning

According to PRIMAS (2013), collaborative work is often associated closely with IBL. They claim that “if students are to make sense of scientific and mathematical concepts, then they will need opportunities to share, discuss and work together” (p.1). MEEF (2011a), also refers to the need for collaborative learning within an IBL setting; “in inquiry-based learning learners are actively engaged in investigations and involved in working out meanings and explanations in groups – through the social construction of knowledge” (p.13).

2.8.1. A definition of collaborative learning

Collaborative learning is defined by Kotsopoulos (2010) and Aelterman, Ruys & Van Keer (2012) as being learning within an environment where students work together towards a shared and individual academic goal. Johnson & Johnson (1996) defined it as “the instructional use of small groups so that students work together to maximize their own and each other’s learning” (p. 786). On the other hand Dillenbourg Baker, Blaye and O’Malley (1996) claim that collaboration “is a social structure in which two or more people interact with each other and, in some circumstances, some types of interaction occur that have a positive effect” (p.21). Dillenbourg et al. define particular positive group interactions as being collaborative, therefore a group may not be collaborative all of the time. Jacobs, Lee and Ng (1997) described collaborative learning as being “organized and managed group-work in which students work cooperatively in small groups to achieve academic as well as affective and social goals” (p.1).

In all definitions, emphasis is on the interpersonal relationship between the group members within a particular learning environment and the way the group goes about a particular task. Another important quality of collaborative work is that students learn how to work together to ensure they all learn and benefit from the activity.
2.8.2. How collaborative learning is included in the local education system

Students learn a lot when they discuss their ideas with peers. Learning through inquiry and collaboration with peers was a suggestion made in the Vision for Science Education in Malta (MEEF, 2011a). In fact the Vision for Science Education cites Gatt and Vella (2003), who define active learning: “learners are actively engaged in investigations and involved in working out meanings and explanations in groups – through the social construction of knowledge” (p. 33). In the finalised National Curriculum Framework for All (2012), which was a much shortened version of the consultation documents (2011a), the authors did not give a detailed description on how collaborative work and IBL can be incorporated in schools. The Vision for Science Education in Malta consultation document (2011a) however also makes reference to Lave & Wenger (1991), to describe how recent educational studies claim that “students learn best when they engage with each other and learn from one another.” This is also described as a “community of practice” (p. 35).

2.8.3. Collaborative learning and student understanding

Gillies, Nichols and Burgh (2011) claimed that since students need to explain their ideas to others during collaborative work, this encourages them to re-examine their ideas and their understanding of the topic before being able to share it with their group.

This idea coincides with Vygotsky’s theory of the zone of proximal development. Vygotsky, as cited by Chaiklin (2003) defined this zone as being “the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers” or “what the child is able to do in collaboration today he will be able to do independently tomorrow” (p. 40-41). According to Taber (2011), “in Vygotsky’s thinking, what is achieved first on the inter-
personal level can become assimilated into the zone of actual development (ZAD), becoming internalised so that it can then be achieved unaided" (p.52).

According to Chaiklin (2003), Vygotsky gave great importance to the effect of the social environment on the learning capabilities of students. When students work on their own on a particular task, they can be said to be at their actual development level. By collaborating with peers or under guidance of a more experienced individual, the student would be able to learn more, this is what Vygotsky refers to as 'potential development level.' Therefore students can be said to learn more effectively when they are working in a collaborative setting where students help each other to learn.

Through collaborative work, students “often develop a better understanding of the problem than they had previously, and this has a positive effect on their learning performance” (Gillies, Nichols and Burgh 2011, p. 427). The NCF (2012), also mentioned the need for learners to be “actively engaged in investigations and involved in working out meanings and explanations in groups- through the social construction of knowledge” (p. 12). By working in groups, students learn how to “communicate, critique, and analyse their work and the work of other students” (p. 22).

2.8.4. How collaborative learning enhances students’ social and life skills

Kotsopoulos (2010) emphasised that through collaborative learning, not only do students work together towards an “academic goal”, but students also learn the “important life skills of working jointly with others on shared problems or challenges” (p.129). Therefore by working in a group, students stand to gain various new skills which they may need later on in life. These skills according to Hardy, Lawrence & Grant (2005) would not be learnt in any other situation. Aelterman, Ruys & Van Keer (2012) claimed that collaborative learning encourages the development of “cognitive learning processes”, “social-emotional functioning” and “psychological development” (p.1).
2.8.5. How should students be grouped for collaborative learning?

When conducting a collaborative learning activity in the classroom it is very important to think about the composition of the groups since group dynamics could influence the outcome of the activity. Gillies and Boyle (2010) carried out a study with 10 teachers about their use of collaborative learning through a semi-structured interview. The teachers who took part in their study discussed the strategies they used in order to group their students. The variety of groups mentioned by the teachers were either mixed gender groups, random groups or friendship groups. With regards to mixed gender grouping the teachers in the study recommended the groups be made up of equal numbers of boys and girls since this ensures that both worked equally and did not outperform each other.

Gillies and Boyle (2010) claimed that the more students were able to influence and inspire each other, the greater their performance on tasks and the more motivated they are. Yet their study also showed that “although friendship was beneficial for performance earlier in the task, it was detrimental later in terms of the errors the students made as they worked collaboratively together” (p.936). Therefore allowing students to work with their friends in a group may be positive since it increases motivation, but this does not necessarily mean that they will carry out the task successfully especially if they get too comfortable in their groups.

Another factor to reflect on when carrying out collaborative work is group size. According to Walker (2007), groups of students should not be composed of more than 2 to 3 students. Small groups encourage students to be more active in the learning process and to participate more since they have more responsibility. It is the teachers’ job to ensure that all students are participating in a lesson and therefore directing questions to all the students in the group would ensure that nobody is left out. Each member in a group should be assigned a particular task, this stops one student from taking over or another student from being left out. This could be done by giving students a particular role to play in the activity for example: “data recorder”, or “group presenter” (p. 89). Students may be allowed to choose which role they would like to play in the activity.
2.8.6. **Difficulties experienced by educators whilst conducting collaborative learning**

Collaborative work is not always an immediate success, in fact Lillejord, Riese, & Samara (2012) claimed that sometimes students do not always go about group work in the correct manner, in fact one of the groups described in their study solves “the problems it encounters by dividing the task into individual subtasks rather than cooperating” (p. 617).

Another problem was described by Kotsopoulos (2010), whose research was with a group of students who were taught how best to go about collaborative work. Although the students learnt how they should work in groups, they still chose not to work collaboratively, for example they chose not to help peers who were weaker. Kotsopoulos observed certain role taking during group work, one student normally took the role of “the foreman” while the other students took on the role of “the labourer” (p.122). In this way not all students were given equal roles in activities. The foreman was the one who directed the progress of the group and told the others what to do; this person took part in the activities in a very minimal way or not at all. The labourers were the students who were expected to do most of the work in the activities like the calculations needed. The labourers in the group were not aided by the foreman of the group and were left out if they could not keep up with the rest of the group. Therefore although students were working within a group, they were not working collaboratively.

Only after self-observation through a video-tape and focus groups with the researchers did students understand what they were doing wrong and what was missing from their collaborative work. The students also understood the importance of everyone in the group learning and feeling valued. Therefore giving students collaborative work is not enough, they need to reflect about what they are doing and discuss their actions with someone who can guide them.
2.9. Conclusion

This chapter gave in depth review of literature on issues which are related to the use of inquiry skills within a collaborative Biology classroom setting. The pedagogy which was explored was that of problem based learning which is a form of inquiry based learning, inquiry based learning being a pedagogy which has its roots in the constructivist philosophy of teaching. The following chapter will explore the research methodology which was used in this study.
Chapter 3

Research Methodology
3.0. Introduction

This chapter will deal with the methodological approaches chosen in order to investigate the research questions. This chapter will describe the setting of the study, the participants, the research tools and how data were collected. Another focus will be on the qualitative research methods which were used and why they were chosen. This chapter will also make reference to the ethical considerations which shaped and guided me in my research.

3.1. The research area

3.1.1. The background setting of the study: choice of location and the participants

The study was conducted in a boys’ church school in Malta. The school was mixed-ability and this helped to give a clearer perspective about whether inquiry based learning and collaborative work is successful with students of different abilities. The school was chosen as I work within it, this was favourable since I was easily given permission to conduct my research and I was familiar with the school, the time-table and students. The students who took part in the research were comfortable working with me and felt at ease especially when they were being observed.

With regards to time management, the fact that I worked at the school proved very advantageous since the focus group discussions and interviews took place during breaks and free lessons. Therefore I could schedule these meetings with the students through the administration team.
The group which was chosen to participate in the study was a group of ten Form 5 students aged between 15 and 16 years who were studying Biology for the SEC examination. There was no sampling in this study as the number of participants was the whole group of students who were in my class.

3.1.2. Receiving authorisation and ethical considerations

Prior to starting my research, I presented a request to conduct research to the Secretariat of Church Schools. Following their acceptance (refer to Appendix 1), I requested the permission of the Headmaster of the school in order to conduct research in the school. After obtaining permission from both the Secretariat and the schools’ Head Master (refer to Appendix 2), I prepared all the documentation which was required in order to obtain ethical approval from the Faculty Research Ethics Committee (FREC). Following the approval of FREC, I submitted my proposal to the University Research Ethics Committee (UREC). After receiving ethical approval, I gave the information sheet and consent forms to the participants of the research and since they were minors I gave another consent form to their parents or guardians (refer to Appendix 2). Following the acceptance of the participants and their parents I started my research.

Although the nature of my study was not particularly sensitive, I made it a point to be careful when it came to ethical issues. This was very important since the case study took place within my own class and the participants were also my students, for this reason care had to be taken to ensure that all ethical considerations were carefully thought of and taken into account prior to starting my research. As I was both the teacher and the researcher, one can say that I had a dual role throughout the study. According to Powell (2011) special care needs to be taken when the researcher is also the teacher.

MacLean and Poole (2010), Powell (2011), and Nolen and Vander Putten (2007) describe three important rules when carrying out research with people; “informed
consent of participants”, “protecting the confidentiality of participants” and “autonomy of participants” (pp. 402-403).

Nolen and Vander Putten refer to informed consent as being the right of research participants and their parents or guardians to be informed and aware of any likely risks which are involved in the research they are being asked to participate in. Informed consent first had to be obtained from the school administration. This was done by firstly explaining the purpose of my study, then assuring them that the Biology topic content would still be covered using methods that were recommended in the syllabus. Finally the school administration was assured that the name of the school or the students involved would not be mentioned in any part of the study. Informed consent was then obtained from the students and their parents or guardians. This was done by explaining the study to them and by giving them an information sheet and consent form (refer to Appendix 2). These gave an account of what the research involved and what was to be expected from the participants; informing them of any risks the research may incur.

Protecting the confidentiality of participants was also an important ethical consideration. This was overcome by not mentioning the name of the school at any point in the study. The names of the participants were changed to pseudonyms to ensure that their anonymity is kept throughout.

The autonomy of the participants was also respected in this study. According to Drew, Hardman and Hosp (2007), “It is also important to understand that consent is seldom (if ever) permanent and may be withdrawn at any time” (p.57). According to Nolen and Vander Putten (2007), “to give consent freely, it is necessary that students, particularly those in the classroom of the teacher conducting the research, feel no implicit pressure to participate” (p. 403). Therefore due to the delicate nature of my dual role, and to ensure that no undue pressure was put on the students who opt-in, it was important to ensure the participants that opting out of the research at any point in time would not harm them in any way or reflect badly on their relationship with me as their teacher. In fact one student did decide to opt out of the study and he chose not to attend the individual interview.
According to Pritchard (2002), it is important for an educational researcher to remember that “practitioners may have a right to devote their own time and effort to research, but they do not have a right to demand the cooperation of others” (p. 5). For this reason all interviews and focus groups were always on a voluntary basis and took place during breaks and not during lesson time. This was described by Powell (2011), as being “process consent” (p.20), whereby “consent is gained for each research tool or at each stage of the research process, rather than an all-encompassing agreement to the whole project at the outset” (p.20). If the participants chose to opt out of the study at any time, they could do so by choosing not to attend the sessions occurring during the break. The class and laboratory lessons related to the study were not optional as normal classroom practice occurred which was beneficial to the students and covered the content required by the syllabus.

3.2. Answering the research questions

The research questions for this study were:

1. Will fifteen year old Biology students be able to apply learnt problem solving skills to a problem solving task, whilst still learning topic content?
2. To what extent do fifteen year old Biology students work collaboratively when dealing with inquiry tasks?

3.2.1. How these questions were addressed

As part of the study, students were given opportunities to work on tasks related to specific inquiry skills (the task was either a written or an oral task), in this way they were guided towards inquiry skills which they then used at a later stage in laboratory investigations related to the topic of “Soil and Agriculture”. The skills which were tackled through the tasks were: working within a group, scientific questions,
constructing hypotheses, variables and fair testing, presenting experimental data and drawing conclusions.

The topic of soil and agriculture was taught through IBL but the focus of the study was on the investigations as through these I could determine whether students could apply the inquiry skills or not.

Students were asked to form groups of not more than 3 students, the students were told to choose who they wished to work with on the inquiry tasks. Students were allowed to work in friendship groups as there is evidence from various studies by Abrami, Chambers, Poulsen De Simone & Howden as cited by Gillies and Boyle (2010) which shows that “students who know and like each other benefit most from working together as they tend to accept more responsibility for their learning and are more motivated to achieve their goals than students who are not friends” (pp. 935-936). As the researcher, I observed the way the students worked on their collaborative tasks, in this way I could understand the group dynamics and whether they were actually working collaboratively or not. Most of the topic of ‘Soil and Agriculture’ was taught through IBL but the main focus of the study was on the investigations as through these I could determine whether students could apply the previously taught inquiry skills or not.

After the inquiry based laboratory task the students participated in a focus group whose aim was to gain insight into the relationship or interactions between the students who were in the same collaborative group. The students were also asked to attend an individual interview where they were asked to solve a problem which required them to apply the skills which they had previously learnt. Apart from the individual problem, they were also asked to answer some questions about how they felt within their groups during the collaborative tasks.

Their knowledge of the topic was also explored through their performance in an end of topic test on ‘Soil and Agriculture’. Six months later the students were given a task which was focused on inquiry skills. This task was carried out to see whether they would retain the inquiry skills at a later stage in the study or whether they would have forgotten them.
3.3. The research strategy

3.3.1. Qualitative research

Qualitative research is described by Devetak, Glažar, & Vogrinc (2010), as being “an exploratory approach emphasizing words rather than quantification in gathering and analysing the data” (p.78). Therefore in qualitative research, the researcher tries to portray his/her findings in a descriptive manner using words rather than numbers to depict his/her results.

The term qualitative research is an umbrella term for many types of research which according to Yin (2011), include: action research, case-study, ethnography, ethnomethodology, feminist research, grounded theory, life history, narrative inquiry, participant-observer study and phenomenological study. Although there are many different types of qualitative research, they all have certain characteristics in common.

According to Yin (2011), qualitative research could be said to be a type of research which focuses on the study of people within a real-world setting doing things and interacting with others within their natural settings. The perspectives and viewpoints of the participants should be represented in the research. The background of the participants should also be described as the background could greatly influence the results obtained. Another feature of qualitative research is that it sets about to explain the results of the study and not just give a description of the events. The last feature of qualitative research is that it is a result of the triangulation of evidence from different sources, for example: observations and interviews. These different sources of data render the study more credible and more trustworthy.

Devetak, Glažar, & Vogrinc (2010), claim that through qualitative research, a researcher is able “to view the world with the eyes of the examinees, to describe and take into account the context, to emphasize the process and not only the final results, to be flexible and develop the concepts and theories as outcomes of the research process” (p.78). This research is qualitative in nature as it uses descriptions in order
to portray the case which was studied and for this reason it was a 'case study'. The features which are unique to case studies are described in the next section.

3.3.2. A case-study

This study can best be described as a case study. According to Creswell (2002) a case study is a problem or situation which is to be studied in depth to achieve an understanding of “a ‘case’ or bounded system, which involves understanding an event, activity, process, or one or more individuals (p.61). Gerring (2004) has a similar definition of case study;

“an intensive study of a single unit for the purpose of understanding a larger class of (similar) units. A unit connotes a spatially bounded phenomenon—e.g., a nation-state, revolution, political party, election, or person—observed at a single point in time or over some delimited period of time” (p.342).

Cohen, Manion and Morrison (2007), also describe the case study as being a study of a particular point in time which is used to demonstrate a more generalizable principle. Another characteristic of the case study was acknowledged by Yin (2003) who defined a case study research as “an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident” (p. 13).

The key characteristics which make up a case study, according to Hitchcock and Hughes, as cited by Cohen, Manion and Morrison (2007), are that they are centred on a very rich and detailed account of events which were related to the case. The description should also explain events in the order in which they took place. Apart from describing the events, the researcher should also combine their analysis of what took place with the description, thus giving a more holistic picture. Another characteristic which makes case studies unique is that they give a particular importance to individuals and groups who are participating in the study and try to understand how they see what is taking place around them. In case studies, the researcher plays a key role in the case and is central to it. The last characteristic they describe is that the
researcher tries to depict the richness of the case they studied when they write their report.

According to Cohen, Manion and Morrison (2007), case studies are able to infiltrate situations in ways which cannot be infiltrated through numerical analysis or through quantitative research. The goal is a holistic picture and depth of understanding rather than a numeric analysis of data” (p.29). The aim of case studies being the attention to details and to the participants in order to develop a theory which can then help other researchers to achieve a better understanding of a case or situation which is similar to the one which was studied.

Yet case studies do not come without flaws, in fact according to Dyer as cited by Cohen, Manion and Morrison (2007), when reading a case study it is important to be aware of the fact that the data being presented would have already been through a selection process which only the author is aware of. Another disadvantage pointed out by Dyer is that case studies follow an “interpretive tradition” (p.257) where the situation is seen through the eyes of the participants and not in a less subjective manner such as through a quantitative manner. In order to overcome these difficulties, different sources of data were collected using a variety of research tools in order to achieve methodological triangulation which would render the results more valid. Effort was made in order to include all the relevant results obtained since this would give an honest insight into the case being studied not just the parts of the truth which would make the data obtained from this study more agreeable and attractive. Therefore it is up to the researcher to justify what they consider to be important and true within a case study research project.

According to Cohen, Manion and Morrison, case studies look at situations and try to understand the cause and effect of what is being studied (a real-life phenomenon); they also put what is being studied in a particular context. In this study a group of students was observed in a particular context. The context of this study was a group of male students between the age of fifteen and sixteen in a secondary church school who chose to study Biology at SEC level. The school was a mixed ability school and the students were not streamed in any way. The students were taught a topic in Biology using a particular methodology and they were observed, interviewed and their
work was scrutinized. All these different methods of data collection were employed to understand the case in question in a more holistic manner.

3.4. The research tools

The following section will explore the research tools used in this study.

3.4.1. Observations

As the researcher I observed the students while they were working in groups, the observations were from the point of view of an educator and researcher. Marshall and Rossman (2006) claim observations are “the systematic noting and recording of events, behaviours, and artefacts (objects) in the social setting chosen for study” (p. 98). According to Ary, Jacobs & Sorensen (2010), in a qualitative setting the researcher uses observation in order to obtain a complete description of a particular setting over an extended period of time. The observations take the form of a narrative which describes “the setting, the behaviours, and the interactions” (p.431), from the perspective of the observer.

In the case of my study, observations took place during the collaborative tasks throughout the research period. I included observations to my data collection methods since I wanted to witness first-hand whether my students were capable of working in collaborative groups. Through my observations I could follow and record the group dynamics, I could also observe whether one person was taking over or whether all students were working equally. Cohen, Manion and Morrison claim that “in observation studies, investigators are able to discern on going behaviour as it occurs and are able to make appropriate notes about its salient features” (p. 260). I could also observe whether all students were able to apply the skills they learnt to the problems at hand or whether they depended on the rest of the group to answer the questions for them.
According to Sherman & Webb (1988) through observation, the researcher is playing two roles: the first being present in the situation and the second is standing aside to observe what is happening. Through observations the researcher can portray the whole group and the situation which they are experiencing, giving a realistic description of what was happening at the time. The researcher can then give a description of what is happening during the research activities from the perspective of an observer. To record my observations, notes were taken during the activities and later on in the day I used my notes in order to write a thick description of what was observed.

There are many different types of observation which depend on the level of involvement of the researcher within the setting being observed. Since I was already a part of the situation which I was observing, the method of observation could be described as ‘participant observation’, yet my role was that of a teacher and researcher and not of a student. A participant in the sense that the students were used to my presence therefore observing them was not intrusive because I was not an ‘outsider’. According to Lofland, Snow, Anderson & Lofland (2005), when a researcher is also a participant, they could be said to be conducting research in “their own ‘nests’” (p. 41), this is advantageous to the researcher as they already know the “cast of characters” (p.41) whom they will be observing. Since I was both the researcher and the teacher this lead to me having a dual role in my research project. This dual role was discussed in section 3.1.2. which focused on ethical considerations.

3.4.2. The focus group

Focus groups were used in this study in order to understand the students' perceptions of the tasks given to them and also to get a deeper understanding of the group dynamics of the students who worked together on the laboratory based inquiry tasks. The questions asked in the focus group can be seen in Appendix 3. This was done through a set of questions which focused on inquiry skills and the students
experiences within the group. The different groups which were composed of three or four students attended one focus group each following the laboratory based tasks. Wilkinson (2004), defines the focus group as “one or more group discussions in which participants focus collectively on a topic selected by the researcher” (p.222). According to Liamputtong (2011), “methodologically, focus group interviews involve a group of 6-8 people who comes from similar social and cultural backgrounds or who have similar experiences or concerns” (p. 3).

In the investigative tasks which were part of this study, students were allowed to group according to friendship; the focus groups were then conducted with the different groups which had formed. Conducting the focus groups with students who had chosen to work together was an advantage. This was also observed by Kitzinger (1994) who concluded from her study that by using pre-existing groups, “we were sometimes able to tap into fragments of interactions which approximated to ‘natural occurring’ data” (p.105). Therefore by using friendship or pre-existing groups in the focus groups, the participants in Kitzinger’s study “often challenged each other on contradictions between what they were professing to believe and how they actually behaved” (p.105).

Although the aim of this research method was to encourage a natural group discussion this truly occurred with only one out of the three groups as they felt very comfortable and were able to discuss among themselves. This probably happened because the students were good friends and this setting resembled the type of natural setting which was described by Kitzinger (1994). In the case of the other two groups the result of the interview more resembled a group interview rather than a focus group as the students took it in turn to answer the questions asked.

Although I observed the different groups whilst they were working, it was also important to see what happened during the collaborative tasks through their eyes and to understand how they felt about their success or failure as a group. According to Cohen, Manion and Morison (2007), “it is from the interaction of the group that the data emerge” (p.376); therefore it was through the discussion during the focus group and through my observations that I could understand their group dynamics.

Yet Kitzinger (1994) also claims that although at times the focus group resembles a natural interaction between groups of people, it is still an artificial set-up which would
not have happened in an everyday situation. In fact Cohen, Manion and Morrison (2007) claim that “focus groups might be useful to triangulate with more traditional forms of interviewing, questionnaire, observation etc.” (p.377). In the case of this study, the data from focus groups, the data obtained from individual interviews and the observations were used in order to obtain a clearer picture of what was occurring. This will be discussed in greater detail in section 3.5.1.

3.4.3. The individual interview

Another data collection method which was used in this study was the individual interview with the participants. According to Tuckman (1999), the interview allows the researcher to peer into “what is ‘inside a person’s head’, makes it possible to measure what a person knows (knowledge or information, what a person likes or dislikes (values and preferences), and what a person thinks (attitudes and beliefs)” (p.237). Tuckman, describes the interview as a technique which “provides methods of gathering data about people by asking them rather than by observing and sampling their behaviour” (p.237). In this way the data which were gathered did not take into account the way the researcher interprets the situation, but only the way the participant perceives it. In the case of my study I could also obtain an insight into the participants’ individual achievement in the written task which was also given to them during the individual interview as discussed in 3.2.1.

A limitation of the interview according to Kvale (1996) is that “the conversation in a research interview is not the reciprocal interaction of two equal partners” (p. 126). Kvale further explains that there is a misbalance of power in an interview, as it is the interviewer who “defines the situation, introduces the topics of conversation, and through further questions steers the course of the interview” (p.126). Therefore it was important to be aware of this situation prior to conducting the interviews and to behave in a manner which would put the participant at ease and encourage them to elaborate further on the questions asked to them.
Before starting the interview I explained the purpose of the questions which were to be asked and I also explained the sequence which was to be followed during the interview. A set of questions were prepared, the questions which were posed to the participants were both of a closed-ended and an open-ended nature. Most of the questions asked were open-ended and this allowed the participants to elaborate as much as they wished on the topic. The questions asked in the individual interview can be seen in Appendix 3.

### 3.5. Validity and reliability

According to Cohen, Manion and Morrison (2007), there are different types of validity and reliability. The definition of validity depends on the circumstances of the research in question. According to Winter (2000) qualitative research is different to quantitative research especially when it comes to validity. In qualitative research there are no “standardized or accepted tests” (p.8) which can test validity. Therefore the validity of a research depends on “the representation of the actors, the purposes of the research and appropriateness of the processes involved” (p.8).

According to Devetak, Glažar, & Vogrinc (2010), an alternative to validity in qualitative research is methodological triangulation, they claim that:

> “Triangulation is not a tool or a strategy of validation, but an alternative to validation. The combination of multiple methodological practices, empirical materials, perspectives, and observers in a single study is best understood as a strategy that adds rigor, breadth, complexity, richness, and depth to any inquiry” (p. 79).

Triangulation in this study will be discussed in section 3.5.1.

Reliability according to Bell (2005), “is the extent to which a test or procedure produce similar results under constant conditions on all occasions” (p.117); these similar results can then give rise to generalisations. Another definition for reliability given by Opie (2004) is that reliability is “an indicator of ‘goodness’ or quality in research” (p. 65).
Opie claims that in some forms of research, such as in a controlled scientific experiment reliability is fairly “unproblematic” (p.66). Yet in a classroom situations certain conditions may be “entirely beyond the researcher’s control, and yet may be of interest to the researcher” (p.66). More often than not in educational research it is difficult to obtain results which can be repeated and for this reason, Opie (2004) states that “reliability would not be a useful criterion to assess the goodness of that particular research” (p. 66).

The participants were in a unique situation at a particular point in time, being taught the topic of “Soil and Agriculture” in Biology through a set of activities which were inquiry and problem based. Opie claims that reliability depends on “the extent to which a data-gathering process produces similar results in similar conditions” (p.68) Therefore although the same technique could have been used with another group of participants then the conditions would change as the participants are different; in fact Opie states that, “if the subjects changed then the conditions would not normally be similar” (p. 68).

In the case of my study, which is a relatively small study, “generalization may be unlikely, but relatability may be entirely possible” (Bell, p. 202). Bassey (1998) claimed that “the task of case study is to produce ordered reports of experience which invite judgement and offer evidence to which judgement can appeal” (p.2). Therefore the case study is the gathering of data about a particular group and it normally focuses on a single study and is very difficult to generalise.

3.5.1. Methodological triangulation

Triangulation is defined by Cohen, Manion and Morrison (2007) as the “use of two or more methods of data collection in the study of some aspect of human behaviour” (p. 141). According to Bell (2005) triangulation is a useful method of cross-checking the findings obtained. Laws (2003), as cited by Bell (2005) claimed that the “the key to triangulation is to see the same thing from different perspectives and thus be able to
confirm or challenge the findings of one method with those of another” (p.116). Laws also warned that sometimes data gathered from different sources or methods may not match. This does not mean that the “data collection process is flawed- it could be that people just have very different accounts of similar phenomena” (p.116). It is then up to the researcher to analyse the results obtained and give a logical reason for them.

In this study several methods of data collection were used. The participants were observed during collaborative work, the collaborative groups then participated in focus groups. Following the focus groups the participants attended an individual interview; data were also collected from the individual task, the end of topic test and the inquiry task assigned six months later. The observations of what took place during the investigative tasks were from the perspective of an educator and researcher. The focus group gave me an insight into the way the students viewed the tasks which they worked on collaboratively and the interactions between the group members. The individual interview focused on each participant and allowed them to express themselves without the rest of the group. The individual task allowed me to understand whether each participant had acquired inquiry skills. The end of topic test showed whether the participants also gained knowledge apart from the skills from the lessons. The ‘surprise’ inquiry task was assigned six months after the lessons took place and focused on whether the students retained the skills which were taught or not.

All these sources of data were different in nature and were utilised in order to obtain a clearer picture which was achieved by looking at the case study from different perspectives.

3.6. The inquiry skills lessons

The first step to creating the inquiry environment was through the ‘inquiry skills lessons’. These lessons were specifically created in order to ensure that students have concrete experience with each of the skills which they will require in order to solve the
problem based inquiry tasks which were given to them at a later stage. The inquiry skills lesson sheets can be seen in Appendix 4. Since the students in this study were in form 5, they already had experience with ‘problem-solving investigations’ in form 3 and 4 as required by SEC in Biology, Chemistry and Physics. Yet although they had previous experiences, which were classified as investigations, they had never been taught inquiry skills explicitly.

According to Seraphin, Philippoff, Kaupp and Vallin (2012), through metacognition, science can be taught in a more “multidirectional, authentic way because it encourages students to become aware of their thinking process and mirror the behaviours of professional scientists” (p.368). Through a specialized meta-cognitive curriculum, the students can, as White and Frederiksen (1998) describe, “learn how to learn” (p.4). Through the investigative or problem based tasks which came after the inquiry skills lessons, I wished to investigate whether students would be able to apply the skills which they had previously learnt to a collaborative laboratory activity and to an individual task.

In order to introduce the study to my students, I explained that we would be learning Biology as a science, ‘the way science is done by scientists’. This intrigued most of them because as a group they study all the sciences, not just Biology; most of the students are highly motivated and enjoy their science lessons. I also explained that the first step towards this journey which we would be taking together was in the form of skills lessons. In these lessons, we explored the main steps required for a successful investigation. These activities involved a number of worksheets which dealt with different science skills.

The activities focused on different aspects of inquiry investigations ‘Working in groups’, ‘Building a hypothesis’, ‘Scientific Questions’, ‘Variables and fair tests’ and ‘How to deal with results’. The ‘working in groups’ task, was chosen in order to help students to reflect on their collaborative skills. The ‘building a hypothesis’ task was important as through my previous experiences with this group, I knew that students found difficulty defining the word hypothesis and writing their own hypothesis.
In the activity related to ‘scientific questions’, the students were given a task where they were shown a particular situation shown in Figure 3.1 (through a PowerPoint slide). They were then required to ask scientific questions about it.

Figure 3.1: Picture used to prompt students to ask scientific questions

Following the brainstorming task, students were then given a hand out related to scientific questions adapted from Levesley (2012). The ‘variables and fair tests’ worksheet which was adapted from Levesley (2012), was important for students to distinguish between different types of variables and to conclude what is required in order to carry out a fair test. The last skill chosen was ‘how to deal with results’, since following a scientific experiment an important skill is presenting the data collected. This was done by presenting the students with a set of experimental data adapted from a 2008 MATSEC Biology examination.

3.7. The investigative tasks

The following sections will look at the different inquiry based investigative tasks which were given to students in the laboratory. These tasks were created by myself and were problem based by nature as their purpose was to place the students in the midst of a problem related to the topic of Soil and Agriculture. Through these investigative tasks
the students could then deduce the different properties of soil which were not previously taught. The investigative task sheets can be viewed in Appendix 5.

3.7.1. Investigating whether soil is composed of various types of particles or whether all soil particles are identical in size and diameter.

The students were given a situation where a couple are walking in the countryside and they start to discuss whether soil is made up of identical particles which are similar in both size and diameter or whether soil is actually formed through decomposition of various rocks and is therefore made up of different particles. After reading the students had to solve this problem by coming up with a suitable laboratory investigation. Figure 3.2 is the worksheet which was given to the students in the laboratory.
In the first investigation I provided students with an everyday situation, with a list of possible laboratory apparatus and with guidelines on what needs to be included in their plan. Therefore according to Fradd et al. (2001) Table 2.2. presented in Chapter 2, the level of inquiry is 4 since the problem is provided by the teacher yet the planning, implementing, reporting and applying were carried out by the students.
3.7.2. Investigating air content in different soils.

The second investigation was based on a farmer asking the students for help when choosing the best soil for his field. He wanted advice on choosing a soil which has high air content. The students were given three soil samples which they had to test and then suggest which would be an ideal soil. Prior to this experiment we did not discuss the different soil types; therefore they were completely new to the students. The following is the worksheet given to the students in the laboratory.

Figure 3.3: Investigation 2 laboratory sheet

Dear Biology student,

I heard that it is very important to have air in the soil... since I heard it contains oxygen needed by many soil organisms.

So I need your advice before I purchase some soil. I managed to get three samples of soil and I would like you to help me choose the one which contains the most air. Can you help me make the right choice?

You are provided with three soil samples, try and determine which sample would be the best choice for the farmer by conducting experiments in the laboratory. Don't forget, you need to compare the different soils.

Notes:

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Unlike the previous experiment, the investigation was more open and less guided. The students were not given any hints with regards to the apparatus which they may need for this experiment, it was up to them to discuss and ask for anything which they may require.
3.7.3. *Investigating water retention properties of different soils.*

The third investigation was based on a farmer asking the students for help when choosing the best soil for her field. She wanted a soil which does not become waterlogged when it rains heavily but at the same time does not drain water too quickly. The students were given three soil samples from which they had to choose the most appropriate one. Prior to these experiments we did not elaborate on the different soil types and their properties. The following is the worksheet given to the students in the laboratory.

**Figure 3.4: Investigation 3 laboratory sheet**

*Figure 3.4: Investigation 3 laboratory sheet*

**Aim:** To determine retention/drainage properties of various soils

*Dear Biology Student,*

*Please help me...I am interested in buying soil to add to my field. I would like to choose a soil which retains water but does not become waterlogged when it rains heavily. At the same time I would not like a soil which drains easily and dries up quickly. Can you think of a way to solve this problem?*

*I left you three soil samples to test...please choose the best one.*

You are provided with three soil samples, try and determine which sample would be the best choice for the farmer by conducting experiments in the laboratory.

Don't forget, you need to compare the different soils.

**NOTES:**

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____________________________________________________________________________________
3.7.4. Investigating water content in different soils.

In the last investigation, the students had to think of a way to investigate the amount of water found in soil. Through their investigation, they could then determine which soil contains the most water. The following is the worksheet given to the students in the laboratory.

Figure 3.5: Investigation 4 laboratory sheet

**Aim:** To determine the water content of a particular soil

_I just realized that perhaps it would also come in handy to know which soil actually contains the most water. Try and think of a method to check how much water a soil contains._

**Notes:**

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These experiments were chosen as they are all suggested by the SEC Biology syllabus and they could be applied to everyday problems experienced by farmers. Students also had to use the results obtained from the experiments to decide which soil was best (according to its properties) and why. Therefore through these inquiry investigations the students were also learning about the characteristics of soil that are usually simply transmitted.
3.7.5. The individual tasks

The individual task was given during the individual interview. There were two inquiry tasks and students who were good friends were not given the same task to ensure that they did not discuss possible methods of solving the problem together. As can be seen below, the students were given a real-life problem which is experienced by farmers, they then had to think of possible solutions to the problem and finally plan an investigation which will prove/disprove their hypothesis. The tasks can be viewed in Appendix 6.

Figure 3.6 and Figure 3.7 illustrate the tasks given to the students:

**Figure 3.6: Individual task A**

Individual Task

A farmer asks you to give him advice... he has a plot of land but the soil found on the land is clay soil; he would like you to help him improve his soil to ensure a good level of production.

Suggest an investigation which can be carried out in the laboratory to check whether your suggestions would work.
3.7.6. The end of topic test

Following the topic of Soil and Agriculture, it was important for me to understand whether learning has taken place and whether the students succeeded in grasping topic content apart from the inquiry skills. Prior to starting the unit of “Soil and Agriculture”, a topic overview was prepared, this can be seen in Appendix 7, this topic overview a list of learning outcomes were identified according to the SEC syllabus. A test was prepared, the choice of questions were chosen to assess whether the learning outcomes were reached. The type of questions asked were similar in nature to those found in past-examination questions. The end of topic test may be viewed in Appendix 8.

Figure 3.7: Individual task B

Individual Task
A farmer asks you to give him advice... he has a plot of land on the side of a hill; he would like you to help him design his field to ensure a good level of production.

- What problems is this farmer experiencing?
- What would your suggestions be to increase production?
- Suggest an investigation which can be carried out in the lab to check whether your suggestions would work.
3.7.7. The inquiry task given six months later

The purpose of the inquiry task assigned six months after the case-study took place was to focus on inquiry skills and whether students retained the skills or not. Since the focus of this task was on inquiry skills, the topic which it was centred around was not related to soil and agriculture, in fact the context was related to whether jelly sets or not with particular fruits. The students were then asked a series of questions which focused on inquiry skills such as writing a hypothesis and fair testing. The task was adapted from the website of ‘Kitchen Chemistry’ from the Royal Society of Chemistry (RSC) (2005). The task on their website was called “Enzymes and Jellies”. Figure 3.8 shows the first page of the inquiry task, the full version of the task can be seen in Appendix 9.

Figure 3.8: Page 1 of inquiry task

Problem to solve...

Jellies are made from gelatine. Gelatine is a protein made from animal products. When it is dissolved in hot water and allowed to cool, gelatine forms a three dimensional network of molecules that holds water rather like a sponge.

Picture taken from http://www.thenakedscientists.com/HTML/content/kitchenscience/exp/science-of-fruit-jellies/

Party jellies are just gelatine with added sugar, fruit flavouring and colouring. Many people like to add fruit to jellies but you will not be able to make jellies with certain fresh fruit such as pineapple, kiwi fruit or papaya – the jelly will not set. However, tinned fruit can be added and the jelly will set without difficulty. N.B. in the tinning process, the fruit is first placed in a hot sugar solution and then it is tinned or placed in a jar with the sugar solution. After the fruit and sugar solution are packed, the jars/cans are then placed in a high temperature water bath for 1.5 minutes. The jars/cans are allowed to cool and they are ready for storage or consumption.
3.8. Analysing the research data

3.8.1. Analysing the qualitative data obtained

According to Quinn Patton (2002), “qualitative analysis transforms data into findings. No formula exists for that transformation. Guidance, yes. But no recipe. Direction can and will be offered, but the final destination remains unique for each inquirer, known only when—and if—arrived at” (p. 432). The data obtained in qualitative research is made up of text rather than numbers, in this study the text being in the form of transcripts of interviews or focus groups, text in the form of written observations and text in the form of students’ work. The job of the researcher being as Schutt (2012) claims to construct a “‘reality’ with his or her interpretations of a text provided by the subjects of the research” (p.321). Schutt also claims that in qualitative research, “analysts seek to describe their textual data in ways that capture the setting or people who produce this text on their own terms rather than in terms of predefined measures and hypotheses” (p. 321-322).

The method of analysis of qualitative data in this study was through the recognition of patterns obtained in the data. According to Quin Patton (2002), this involves searching the text obtained in order to recognize “recurring words or themes” (p. 453) which serves to “identify core consistencies and meanings” (p.453). Therefore all the data obtained were analysed for common themes and patterns which then served to build my discussion of the results.

In the case of this study the method of analysis was of an inductive approach, Quin Patton (2002), describes this method as a method which “involves discovering patterns, themes, and categories in one’s data. Findings emerge out of the data, through the analyst’s interactions with the data, in contrast to deductive analysis where the data are analysed according to an existing framework” (p.110). Therefore first the data were read in search of patterns and themes; these were identified from the text data and they were then analysed according to the relationships which emerged between the themes and categories.
3.9. Conclusion

This chapter presented the background details of the study, the rationale of the study, the research questions and how they were addressed. It also presented the methods and procedures used in order to collect data and the reasons for choosing these methods. Another objective of this chapter was to present the procedures used in order to move from the data collected to the findings which are presented in the next chapter.
Chapter 4

Results and Discussion: Putting Skills into Practice
4.0. Introduction

This chapter will discuss the extent to which the students were able to apply the skills learnt to a new problem. They were first given a set of investigative tasks to solve within a collaborative group; these tasks were described in Chapter 3. Within these groups the students were able to help and work with each other. Following the collaborative investigative tasks, the students were given an individual task which they had to solve during an interview; the individual task was described in Chapter 3. This individual task gave a clearer understanding of whether or not the students could solve a problem without the aid of their peers and also whether they could apply the inquiry skills they learnt to a particular problem when they were on their own. Another inquiry related task was given to the students after six months to determine whether the skills were retained by the students or whether they were forgotten with time.

The aim of this chapter will be to discuss whether the students were able to apply inquiry skills to a problem both in a collaborative setting and individually. The characteristics of particular students who responded to the inquiry process in a unique way will be discussed in more detail in the form of short “case studies.” The chapter will also discuss whether students acquired the knowledge on ‘Soil and Agriculture’ through an IBL pedagogy.
4.1. Were students capable of applying skills learnt to tasks given both collaboratively and individually?

4.1.1. Identifying the aim of the problem collaboratively

The students worked in groups on four investigations all of which required the identification of an aim from the problem statement. The aims provided by the groups are described below.

Investigation 1: Investigating whether soil is composed of various types of particles or whether all soil particles are identical in size and diameter.

The first task given to the students can be seen in Appendix 5. The aims given by the three groups were as displayed in Table 4.1. Groups B and C gave accurate aims as they described how soil particles would separate according to size or mass, yet group A’s aim showed that they already knew what the outcome of the experiment would be as they knew the result would be that the soil particles form layers.

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<thead>
<tr>
<th>Group</th>
<th>Aim</th>
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<tbody>
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<td>A</td>
<td>The different layers of soil</td>
</tr>
<tr>
<td>B</td>
<td>How particles of soil vary in size</td>
</tr>
<tr>
<td>C</td>
<td>Differences in size and diameter of soil particles</td>
</tr>
</tbody>
</table>
Investigation 2: Investigating air content in different soils.

Table 4.2 below shows the aims given by the groups for the second investigation. Groups B and C correctly gave the aim of the experiment as they compared air content in different soils. On the other hand group A associated air content with oxygen content; thus forgetting about all other gases which could exist in soil.

Table 4.2: Aim given by groups for investigation 2

<table>
<thead>
<tr>
<th>Group</th>
<th>Aim</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>The amount of oxygen in soil</td>
</tr>
<tr>
<td>B</td>
<td>The volume of air in different types of soil</td>
</tr>
<tr>
<td>C</td>
<td>Which soil contains the greatest amount of air</td>
</tr>
</tbody>
</table>

Investigation 3: Water retention properties of different soils.

As can be seen from Table 4.3, all groups understood what the aim of the investigation was; group A also addressed the need to find ‘the best soil’ in terms of its water retention properties. Group C included time in their aim, which gives an indication as to how they intended to measure water retention.

Table 4.3: Aim given by groups for investigation 3

<table>
<thead>
<tr>
<th>Group</th>
<th>Aim</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>To investigate which soil is best to retain water but doesn’t become waterlogged and which doesn’t drain easily</td>
</tr>
<tr>
<td>B</td>
<td>To investigate water retention of each soil</td>
</tr>
<tr>
<td>C</td>
<td>The time it takes for the water to pass through the soil</td>
</tr>
</tbody>
</table>
Investigation 4: Investigating water content in different soils.

The problem posed to the students in investigation 4 was straightforward and so they found it easy to determine the aim of the investigation, as is evident from Table 4.4.

Table 4.4: Aim given by groups for investigation 4

<table>
<thead>
<tr>
<th>Group</th>
<th>Aim</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>To see which soil has the most water</td>
</tr>
<tr>
<td>B</td>
<td>To investigate how much water content is naturally found in soil</td>
</tr>
<tr>
<td>C</td>
<td>To test how much water the soil contains</td>
</tr>
</tbody>
</table>

4.1.2. Identifying the aim of the problem at hand individually

When the students were given the problem to solve individually, they were given time to reflect on the problem given they then thought of an investigation which could be carried out in a laboratory setting to test their hypotheses. The students were given a planning sheet identical to the one they had used within a collaborative setting. Two different problems were prepared to avoid close friends discussing what they did with others who had not yet done the individual interview. The first thing they did was state the aim of the investigation they would be carrying out.

Most of the students (eight out of the nine students) who attended the individual interview were capable of identifying the aim of the investigation they had to plan in order to solve the problem. In fact only one of the students did not identify the correct aim, this student was Sven; Sven’s case will be discussed in detail in 4.5.1.

The names used in this study are all pseudonyms in order to protect the identity of the participants. Other students who had the same problem to solve, suggested other aims, for example Ben and Dale suggested the use of terracing and the addition of
rubble walls to decrease soil loss. Dale’s aim was “The effects of terracing and rubble walls on water and nutrients in a field found on the side of a hill”. The other problem which some of the students were given to solve was how to improve the soil of a field which was mostly composed of clay soil. The aims given by James and Michael revolved around the addition of lime or humus to increase soil crumb diameter.

Most students were able to apply what was previously learnt in class to the problem at hand and they were also capable of identifying the correct aim to the problem they were supposed to solve.

4.1.3. Discussion: Were students capable of identifying the aim of the problem?

Overall the students succeeded in identifying the aim of the investigation they were about to carry out and to identify the problem to be solved. When doing collaborative work, the only group who did not identify the correct aim in all the experiments was group A. In the first investigation, Martin, one of the students from Group A ‘gave away’ what the group should expect from the results of the experiment, since he said that the aim is to see ‘the different layers of soil’. The same problem was observed when the students carried out the second investigation, the aim which was given by this group was “to find the amount of oxygen in soil” when in reality they had to find the amount of air in soil.

Later on in the focus group it became clear that that Martin had already covered the material at private tuition lessons and therefore his prior knowledge interfered with the inquiry process through which the group should have proceeded. The other members of the group did not question his reasoning since he was ‘more experienced than them’ even though finding different layers of soil, or finding the amount of oxygen in soil were clearly not the aim of the investigation which they had to carry out.
Prior knowledge plays an important role in the inquiry process, according to Prince and Felder (2006):

“New information is filtered through mental structures (schemata) that incorporate the student’s prior knowledge, beliefs, preconceptions and misconceptions, prejudices, and fears. If new information is consistent with those structures, it may be integrated into them, but if it is contradictory, it may be memorized for the exam but is unlikely to be truly incorporated into the individual’s belief system- which is to say, it will not be learned” (p.126).

In the case of Martin, the prior knowledge was the description of the soil laboratory experiment which he learnt during private lessons. Through these lessons Martin could remember the expected results of a soil profile. Unfortunately Martin was not capable of incorporating what he already knew to the problem at hand, he could only remember the results which one should expect to be obtained. Martin’s group depended on him to think of the aim of the investigation and they just accepted his suggestions. Later on, in a focus group when the group was asked whether they all contributed equally, Jake said “most of the time we all contributed to what was being done but sometimes especially in the beginning Martin was taking over. Martin had already covered the topic at private lessons so he knew how to carry out the method.” From these observations, there are indications that sometimes prior knowledge can hinder the inquiry process. Inquiry requires students to have a real question or problem. If students already know what they will find, this defeats the purpose of the task. Martin chose not to participate in the individual interview and the inquiry test (carried out at a later stage) therefore it was not possible to compare his ability to apply the inquiry skills to a particular problem individually with his achievement within a group.

Through the individual problems, each individual’s abilities, strengths and weaknesses became much clearer. Overall most of the students (8 out of 9), were able to identify the aim of the problem they were to solve, therefore I could conclude that they grasped the skill of writing an aim. The only student who did not successfully identify the aim and had difficulties solving the problem was Sven. Sven’s case will be dealt with in depth in section 4.5.1.
4.2. Making a prediction and giving a scientific reason for their prediction

4.2.1. Making a prediction and giving a reason for their prediction collaboratively

The next thing that the students did was make a prediction. According to Hodson (1998), everyone makes predictions in their everyday life yet what makes a prediction scientific is “the utilization of relevant and appropriate science concepts in pursuit of scientific purpose” (p. 24).

In the planning sheets of the investigation the students continued the statement ‘This is what I think will happen…” in order to give their prediction, they then had to give “The reasons for thinking this…” The following tables: Table 4.5- Table 4.8 show the different predictions and reasons given by the student groups for the different investigations.

Investigation 1: Investigating whether soil is composed of various types of particles or whether all soil particles are identical in size and diameter.

Table 4.5 Prediction given by groups for investigation 1

<table>
<thead>
<tr>
<th>Group</th>
<th>Prediction</th>
<th>Reason for thinking this</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>I predict that the bigger the soil particle, the denser it is and it will sink according to its density, the lighter the particle the higher it will stay.</td>
<td>Particles separate because of their density.</td>
</tr>
<tr>
<td>B</td>
<td>I think that the large soil particles will sink to the bottom of the measuring cylinder and the small ones will remain on top.</td>
<td>Each soil particle has different densities and they will separate in layers according to their densities.</td>
</tr>
<tr>
<td>C</td>
<td>I think that large particles will sink to the bottom.</td>
<td>This is because the bigger particles are denser.</td>
</tr>
</tbody>
</table>
Investigation 2: Investigating air content in different soils.

Table 4.6: Prediction given by groups for investigation 2

<table>
<thead>
<tr>
<th>Group</th>
<th>Prediction</th>
<th>Reason for thinking this</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>I think that the water will move the oxygen.</td>
<td>The gas has a lower density than water so the gas will move up.</td>
</tr>
<tr>
<td>B</td>
<td>I think that the soil which has the most air is the one in which the greatest difference in soil volume is noted.</td>
<td>When soil is added to water the air will be displaced by the water and the air will escape, as a result the soil volume will decrease.</td>
</tr>
<tr>
<td>C</td>
<td>I think that the water will replace the air spaces therefore reducing the volume.</td>
<td>Because air is lighter than water, so water is going to displace the air.</td>
</tr>
</tbody>
</table>

Investigation 3: Water retention properties of different soils.

Table 4.7: Prediction given by groups for investigation 3

<table>
<thead>
<tr>
<th>Group</th>
<th>Prediction</th>
<th>Reason for thinking this</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>I think that the clay soil will hold the most water.</td>
<td>Usually clay is very good at holding a good amount of water</td>
</tr>
<tr>
<td>B</td>
<td>The soil which contains the least air present in it will be the one which holds the most water.</td>
<td>The bigger the soil particles, the more air spaces there are between them and therefore the less water is held in the soil.</td>
</tr>
<tr>
<td>C</td>
<td>The most porous soil will take longer for water to pass.</td>
<td>The soil will absorb water.</td>
</tr>
</tbody>
</table>
Investigation 4: Investigating water content in different soils.

Table 4.8: Prediction given by groups for investigation 4

<table>
<thead>
<tr>
<th>Group</th>
<th>Prediction</th>
<th>Reason for thinking this</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Loam soil contains the most water</td>
<td>By the appearance of the soil</td>
</tr>
<tr>
<td>B</td>
<td>The soil which has the smallest particles will be the one which holds the most water</td>
<td>I think this because tiny soil particles will contain the most water.</td>
</tr>
<tr>
<td>C</td>
<td>Clay soil will have the most water</td>
<td>I think this because it looks very wet in comparison to the other soils.</td>
</tr>
</tbody>
</table>

4.2.2. Making a prediction and giving a reason their prediction: collaboratively

In the collaborative tasks in the first investigation, all the groups were capable of predicting what will be the outcome of their investigation. All the groups were also capable of giving a scientific reason for their prediction, since they all made reference to ‘density’ to explain the phenomenon they predicted. At this stage of the investigation, what was most important was their ability to put forward a plausible prediction rather than a correct prediction. In the second investigation: all groups predicted that when water is added to soil, the soil will displace any air which was found in the soil. Group A failed to make a distinction between air (and all the gases found in it) and oxygen (the only gas required by living organisms for respiration).

In the third investigation, group A made reference to clay soil even though we had never mentioned the different soil types before the investigations. Martin applied his prior knowledge of soil and used this knowledge to predict the outcome of the experiment. On the other hand the other groups did not have prior knowledge about what to expect in the experiment but they used the results of the previous investigations to help them to predict what would take place in the current one. This is most evident in group B’s prediction who used the results of the previous investigation to predict the current one. Group C also used the previous experiment to predict the current one yet their prediction shows that perhaps they were unsure of the meaning of the word ‘porous’ since the
reason they gave for their prediction was that it will ‘absorb more water’ which is incorrect. Vocabulary and language can sometimes interfere in the way students express themselves especially in science which has a unique language.

In the fourth investigation the students in group A were again influenced by Martin, yet were unable to give a scientific reason for their prediction. Martin clearly had misconceptions since he should have known that clay soil is the soil which retains the most water and not loam soil. Martin probably learnt things which he learnt in private lessons by heart and for this reason he did not attempt to reason, think and observe like the other students. The other students were able to arrive at better conclusions by observing and basing the reasons for their predictions on evidence observed. In fact Group B made a correct prediction for the investigation yet the reason for thinking so was incorrect since they thought that water is actually inside the soil particles and not around them. Group C based their prediction on the appearance of the soil and this was correct because clay soil appears to contain water when compared to other soils.

4.2.3. Making a prediction and giving a reason for their prediction: individually

For the individual task, the students had to think of an appropriate prediction for their proposed investigative method. Apart from a prediction, the students also had to give a scientific reason for their prediction. Therefore it was important to establish whether the reason behind the prediction was correct or not.

Most of the students were successful in identifying an appropriate prediction and giving a correct scientific reason for their choice of prediction in the problem which was given to be solved individually. In the problem related to having a field with clay soil Task A (Appendix 6), all three students suggested the addition of lime or humus to clay soil in order to increase the diameter of the soil crumb and as a result this would improve water drainage and air retention properties. In the problem related to having a field on a hill, Task B (Appendix 6), Ben, Lee, Dean and Jake gave similar predictions since they claimed that by adding a rubble wall and terracing, less soil will be lost from the field.
An example of a prediction given by Lee was “when the rubble walls are added there will be less flooding of water and less loss of soil because the rubble wall acts like a filter for excess water and will not let soil fall down the hill.” Although these predictions and reasons were all different, they were all referring to the same thing since all the students suggested the addition of terracing or rubble walls to decrease water and soil loss.

4.2.4. Discussion: Were students capable of making a prediction?

Overall the students were successful when identifying a prediction for the problem given, both in a group and individually. When discussing students’ abilities to use hypotheses, Micallef (2010) claimed that “students are not used to being given statements which they have to test out” (p. 80) in fact 47% of the students in her study did not give a properly worded hypothesis. This contrasts greatly with the results obtained in the individual task. All the students who participated were capable of writing a hypothesis / prediction for the outcome of the investigation they were planning. Sometimes the students’ wording of the hypothesis was not in the ‘If….then….statement’ format as was recommended in the inquiry skills lessons. Therefore although the students knew the purpose of a hypothesis, not all the students were able to word the hypothesis in the required or expected manner.

4.3. Choosing a method to test their prediction

4.3.1. Choosing a method to test their prediction: collaboratively.

The students were required to provide an appropriate method to test their prediction. They also had to think of the apparatus required, variables which they will vary or keep
constant, precautions and fair testing. The following tables illustrate the answers given by the students in the investigations.

**Investigation 1: Investigating whether soil is composed of various types of particles or whether all soil particles are identical in size and diameter.**

Table 4.9: The apparatus, method, variables and means of fair testing/ precautions given by the groups for investigation 1

<table>
<thead>
<tr>
<th>Group</th>
<th>Apparatus</th>
<th>Method</th>
<th>Variables</th>
<th>Fair testing/ precautions</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Beaker, spoon.</td>
<td>1. Place some soil in a beaker. 2. Add some water and with a spoon mix the soil with the water. 3. Let the soil inside the beaker settle and the soil layers will form.</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>B</td>
<td>Measuring cylinder, soil, teaspoon and water.</td>
<td>1. 150 cm³ of water will be added to the measuring cylinder. 2. 7 teaspoons of soil will be added to the measuring cylinder and it will then be shaken. 3. Observations are noted.</td>
<td>No variables will be changed because only 1 volume of water and soil will be recorded.</td>
<td>The volume of water will be read at eye level.</td>
</tr>
<tr>
<td>C</td>
<td>Measuring cylinder, spoon, sieve, water and beaker.</td>
<td>1. Sieve the large particles out to obtain the small particles. 2. Put the smaller particles into a measuring cylinder and wait for the particles to settle according to size and density.</td>
<td>N/A</td>
<td>Not disturbing the soil while it settles.</td>
</tr>
</tbody>
</table>

As can be seen from the Table 4.9 all three groups came up with different methods to solve the problem yet they all managed to ‘solve the problem.’ Figure 4.1, illustrates the results obtained by group A. PBL and IBL laboratory activities are unlike a normal laboratory setting where students are given the steps to carry out an experiment and everyone does everything in the same way. According to Walker (2007), in an IBL setting students “are doing more than simply doing an experiment, they are working like real scientists” (p. 9). The fact that students were ‘open’ to carrying out the
investigation or solving the problem however they wanted to, gave them a chance to be both creative and unique.

Figure 4.1: Group A's soil profile
Investigation 2: Investigating air content in different soils.

Table 4.10: The apparatus, method, variables and means of fair testing/ precautions given by the groups for investigation 2

<table>
<thead>
<tr>
<th>Group</th>
<th>Apparatus</th>
<th>Method</th>
<th>Variables</th>
<th>Fair testing/ precautions</th>
</tr>
</thead>
</table>
| A     | Measuring cylinder, beaker and spoon. | 1. An amount of soil was poured into the measuring cylinder.  
2. Water was poured in the measuring cylinder with the soil.  
3. The measuring cylinder was shaken to mix the water with the soil.  
4. The level of soil and water was measured to see how much they decreased. | Different types of soil. | N/A |
| B     | 6 Measuring cylinders, soil, teaspoon and water. | 1. Prepare 6 measuring cylinders. (3 filled with 150cm$^3$ of water and 3 filled with 50cm$^3$ of different soils.  
2. Pour the soils in the different measuring cylinders and shake them.  
3. Record the final volume and calculate the difference in volume. | The same volume of water and soil will be used for each sample. | 1. Measuring cylinders are read at eye level  
2. Measuring cylinder is placed on a flat surface. |
| C     | Measuring cylinder, 2 beakers, 3 soil samples and water. | 1. Measure the volume of soil and the volume of water separately.  
2. Add them to each other in a measuring cylinder. Take the volume of both together.  
3. Add the original volumes together and deduct the final volume (this will be the volume of air). | Volume of water and soil | Not disturbing the soil while it settles. |

As can be seen from Table 4.10, all three groups thought of similar methods to solve the problem even though they were not provided with a list of apparatus. The main difference between the groups was their level of accuracy; for example it was only group B who mentioned using a known volume of both soil and water.

The students still found difficulty in distinguishing between experimental variables and fixed variables, it was only group A who realized that the only variable in this experiment should have been the type of soil which was being used in the experiment.
Students also found difficulties when thinking of precautions for their investigations. From my observations, it was clear that students think of precautions when coming up with their method but then find it difficult to explain precautions taken in their laboratory reports.

Figure 4. 2: Group B’s experimental set-up for investigation 2
Investigation three: Water retention properties of different soils.

Table 4.11: The apparatus, method, variables and means of fair testing/ precautions given by the groups for investigation 3

<table>
<thead>
<tr>
<th>Group</th>
<th>Apparatus</th>
<th>Method</th>
<th>Variables</th>
<th>Fair testing/ precautions</th>
</tr>
</thead>
</table>
| A     | 4 Measuring cylinders, 2 beakers, filter funnel, soil, filter funnel and spoon | 1. 50cm³ of soil A was put in a measuring cylinder.  
2. Then soil A was placed in the filter funnel on a filter paper.  
2. 40cm³ of water poured on the soil that was on the filter paper.  
3. The amount of water in the measuring cylinder was recorded after 1 minute.  
4. The same procedure was repeated for soil sample B and C. | Different types of soil. | N/A |
| B     | Stopwatch, 4 measuring cylinder, 3 soil samples, water, filter paper, filter funnel and spoon | 1. Place the filter paper in the filter funnel, put 20cm³ of one soil sample in the filter paper.  
2. Place the filter funnel on the measuring cylinder.  
3. Add 20cm³ of water to the soil.  
4. Record the volume of water in the measuring cylinder for 10 minutes, taking readings at 2 minute intervals.  
5. Repeat the experiment for the other soil samples. | Type of soil | 1. Measuring cylinders are read at eye level  
2. Measuring cylinder is placed on a flat surface |
| C     | Beaker, funnel, filter paper, measuring cylinder and water. | 1. Measure equal amounts of water for each soil sample.  
2. Set up the filter paper inside the filter funnel. Place the soil inside the filter funnel.  
2. Add the water and record how much water passed through the soil in 5 minutes. | Type of soil | Not disturbing the soil while it settles. |

All the groups thought of similar ways of solving the problem yet their methods were different. For example groups B and C set a period of time and saw how much water passed through the different samples. Group B was more accurate since they took
regular readings throughout. On the other hand group A said they would pour water and observe how much water passes through the soil in 1 minute. Their method would have been more accurate had it included more readings. With regards to measurements of soil and water, groups A and B were clear about how much soil and water to include in the experiment. Group C stated that the same amount of water was used in each experiment yet they did not mention the need to measure the amount of soil. Figure 4.3. shows Group B’s experimental set-up.

**Figure 4.3: Group B’s experimental set-up for investigation 3**

In this experiment, all the groups mentioned the right variables for this experiment since they all mentioned ‘type of soil’ to be the only variable changed. On the other hand groups A and C still found it difficulty when thinking of precautions for the experiment planned. Group B stuck to the same precautions which they used in the previous experiment since they worked on both of them on the same day.

After conducting the experiment according to their method, group C decided to try a different method. Instead of using filter paper, they decided to put wire gauze in the filter funnel since they thought this would be more accurate. Had this been the normal laboratory situation, this group would not have been given the opportunity to try a different method since they would normally be following a ‘recipe-type’ investigation and would be pressed for time. Yet since the topic of soil was being taught through an inquiry based pedagogy it was important for me that my students were able to experience a genuine investigative laboratory experience.

According to Hofstein and Lunetta (2003) the word inquiry “also refers to more authentic ways in which learners can investigate the natural world, propose ideas, and
explain and justify assertions based upon evidence and, in the process, sense the spirit of science” (p.30). Hofstein and Lunetta cited the work of Gunstone and Champagne (1990) who claimed that meaningful learning would occur in the laboratory if students were given enough time to both interact and reflect on the experiment they are carrying out. They also claimed that students are normally not given sufficient time or the opportunity to conduct laboratory experiments in this way “since they are usually involved in technical activities with few opportunities to express their interpretation and beliefs about the meaning of their inquiry” (p. 32).

Since group C clearly reflected on possible sources of error in their previous method, it was important to allow them to try their alternative method before starting the fourth investigation. When we discussed the results obtained using the different methods, the students then reflected on which method was more successful in reaching the aim of their investigation.
### Investigation four: Water content of different soils

**Table 4.12: The apparatus, method, variables and means of fair testing/ precautions given by the groups for investigation 4**

<table>
<thead>
<tr>
<th>Group</th>
<th>Apparatus</th>
<th>Method</th>
<th>Variables</th>
<th>Fair testing/ precautions</th>
</tr>
</thead>
</table>
| A     | Desiccator, stop watch, Bunsen burner, crucible, tongs. | 1. The weight of the crucible was measured.  
2. The weight of the crucible with the soil was measured and recorded as $M_1$.  
3. The crucible with the soil was heated over a Bunsen burner.  
4. The crucible with the soil was cooled in a desiccator and weighed, this was recorded as $M_2$.  
5. Water in the soil was found by calculating $M_1 - M_2$. | Type of soil | No precautions. |
| B     | Crucible, Bunsen burner, tripod, electronic balance, stop watch, spoon and 3 soil samples. | 1. Weigh a clean, dry crucible. Add soil in the crucible and weigh again.  
2. Place the crucible on a tripod and heat for 1 minute.  
3. Weigh the crucible and contents again.  
4. Repeat the experiment again until a constant mass is achieved. | The temperature | - Tare the electronic balance before using it.  
- Avoid drafts of wind when conducting the experiment. |
| C     | Desiccator, Bunsen burner, electronic balance, thongs, crucible. | 1. Place 20g of soil inside a crucible and weigh them together.  
2. Heat the crucible on a Bunsen burner and heat for 2 minutes, allow cooling and weigh again.  
3. The crucible is placed in a crucible during cooling to decrease water losses.  
4. This procedure is repeated until the mass remains constant.  
5. The amount of water in soil is found by subtracting the final mass from the original one. | Type of soil | - Use the same amount of soil in each experiment for fair testing. |

All the groups thought of a suitable method to solve the problem given to them. Groups A and C included a desiccator and they chose to do so because they had recently used this piece of equipment in Chemistry and they decided to apply what they learnt in Chemistry to the problem at hand. One student from group C said “Miss, can we
use the desiccator found in the Chemistry lab? I really think it would make our experiment much more accurate since we would not be allowing moisture in the air to become part of the soil!” Therefore, not only were students using skills taught in the inquiry skills lessons but they were also applying what they learnt in Chemistry to the problem at hand. Figure 4.4. shows group C’s experimental set-up.

Figure 4.4: Group C’s experimental set-up for investigation 4

4.3.2. Choosing a method to test their prediction: individually.

For the problem related to having a field on the side of a hill, three out of six students decided to build a model of a hill, one side with a slope and the other adapted according to their recommendations, for example by adding terracing or barriers which represented a rubble wall, or both additions together. An example of a method which was proposed to decipher between the introduction of a rubble wall and no rubble wall was that of Steven. Steven’s proposed method was to have two colanders and in one of them to place a layer of rocks which would resemble a rubble wall, this would be topped with soil. In the other colander to place just the soil (similar to a hill with no rubble walls) and then to measure the volume of water which passed through each colander for a particular period of time.
The other two students did not propose a method which would solve the problem posed to them. Sven was one of the students who found great difficulty when thinking of a plausible method while he was working alone. Jake also proposed a method which would not solve the problem; he proposed placing a sample of the soil from the field in the filtration set-up and then observing the water lost from the sample. His method did not solve the problem and during the individual interview he was often lost and unsure about how to progress. Jake’s case will be dealt with in detail in section 4.5.4.

In the other problem which was a farmer having a field containing clay soil, two out of three students were capable of producing a method to test their prediction. These two students concluded that when lime or humus are added to the soil and mixed, the soil crumbs become larger and so the air spaces increase between them. Therefore their method revolved around making the soil crumbs larger and then testing the amount of air found in soil by using the displacement of air method and comparing their result with another experiment or where clay soil is tested in the same way. Their methods revolved around finding the percentage air content in both clay soil and treated clay soil. Agricultural methods of improving clay soil were discussed in class prior to the task but these students were able to apply the method they used in the second investigation to the problem given. On the other hand James, who had proposed a correct prediction, did not succeed in choosing the right method to test his prediction.

All the students were capable of choosing the correct apparatus to carry out the investigation which they planned. Yet students still found difficulties when describing the variables and precautions of their investigation. In the hill problem, four students out of six were capable of identifying the variables correctly and describing suitable precautions. For example Dean’s variable was the structure of the hill in both models and his precautions were using “the same volume of water, the same hill steepness and the same type of soil in both set-ups.” All these precautions were correct and specific to the experiment being proposed. In the problem related to a field of clay soil, Dale and Michael were both capable of identifying the variables in their investigation yet James struggled in doing so. Dale and Michael mentioned presence or absence of lime/ humus in their variables. They then mentioned using the same volume of soil and water in their precautions.
Overall in both problems A and B, three out of nine students were unable to identify suitable variables for the experiments they planned. One student, James, did not identify any variables and his precaution was “*compare to a control for fair testing*” when he should have actually proposed a control. This indicates that he knew what was needed but he could not apply it to the experiment at hand.

4.3.3. Discussion: Were students capable of choosing the right method to test their prediction?

When the students were in groups it was easier for them to devise a method and then think of the variables and methods of fair testing as a group. When the task was individual some students struggled whilst others were both fast and self-confident when devising a method which would test their prediction. The students, who found most difficulty when working individually, were James, Jake and Sven. James and Jake were both average achievers, yet they succeeded in fulfilling all the tasks successfully whilst forming part of a collaborative group with Martin who was of a slightly higher achievement level. When conducting the tasks individually both James and Jake struggled as they both found difficulties when thinking of a method to test their prediction. According to Shachar (2003), students who are low-achievers are the ones who benefit the most from collaborative work as they improve significantly when placed in a collaborative setting. The reason being because low achievers, tend to follow or copy what students who are of a higher achievement level in their groups recommend. James and Jake benefitted the most from being in a collaborative group and these results are consistent with those in Shachar’s study. On the other hand Sven who is normally a high achiever also found great difficulties when working individually; therefore it is not only the low achievers who gain from being in a group but also high achievers who have difficulties when it comes to problem solving.

Overall most of the students who participated in the study were capable of describing an appropriate method which they could have used to test their prediction. Students
still found difficulties when identifying the variables in the experiment they planned and thinking of appropriate ways of ensuring fair testing.

4. 4. Collecting and displaying results

4.4.1. Collecting and displaying results collaboratively

As part of their planning, students also had to think of ways in which they could record and then display their results. Tables: 4.13-4.16 show the methods the groups chose to record and display their results.

Investigation one: Investigating whether soil is composed of various types of particles or whether all soil particles are identical in size and diameter.

Table 4.13: Methods of recording and displaying results for investigation 1

<table>
<thead>
<tr>
<th>Group</th>
<th>Record</th>
<th>Display results</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>By measuring the thickness of the soil layers</td>
<td>In the form of a table</td>
</tr>
<tr>
<td>B</td>
<td>Explaining how different levels of soil will come about</td>
<td>Drawing a diagram illustrating the different levels of soil</td>
</tr>
<tr>
<td>C</td>
<td>Observe the different layers of soil formed</td>
<td>Through a photograph of the results obtained</td>
</tr>
</tbody>
</table>
Investigation two: Investigating air content in different soils.

Table 4.14: Methods of recording and displaying results for investigation 2

<table>
<thead>
<tr>
<th>Group</th>
<th>Record</th>
<th>Display results</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Measuring how much the level of water and soil decreases.</td>
<td>In the form of a table</td>
</tr>
<tr>
<td>B</td>
<td>In a table.</td>
<td>By plotting a bar graph to show differences between the different soils.</td>
</tr>
<tr>
<td>C</td>
<td>Calculate the difference in volume between the original volume and the final one.</td>
<td>In the form of a table.</td>
</tr>
</tbody>
</table>

Investigation three: Water retention properties of different soils.

Table 4.15: Methods of recording and displaying results for investigation 3

<table>
<thead>
<tr>
<th>Group</th>
<th>Record results</th>
<th>Display results</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>By using a stop watch and reading the amount of water in the measuring cylinder.</td>
<td>In the form of a table</td>
</tr>
<tr>
<td>B</td>
<td>In a table.</td>
<td>By plotting a line graph to show differences between the different soils.</td>
</tr>
<tr>
<td>C</td>
<td>By using a stopwatch and measuring cylinder</td>
<td>In the form of a table.</td>
</tr>
</tbody>
</table>
Investigation four: Water content of different soils

Table 4.16: Methods of recording and displaying results for investigation 4

<table>
<thead>
<tr>
<th>Group</th>
<th>Record results</th>
<th>Display results</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>In a table</td>
<td>In a table</td>
</tr>
<tr>
<td>B</td>
<td>In a table.</td>
<td>By plotting a line graph to show differences between the different soils.</td>
</tr>
<tr>
<td>C</td>
<td>By measuring the weight at regular time intervals and then calculating the difference in weight. From the results calculating the % change in mass.</td>
<td>In a table</td>
</tr>
</tbody>
</table>

While planning their investigations, students chose a way of recording and displaying the results of their investigation. Most of the groups chose to display their results in the form of a table, the most probable reason for this being the fact that they present results in a tabular manner in many scientific experiments.

On the other hand group B thought of different ways of displaying their results. For example in the first investigation they said they would draw a diagram illustrating the different layers of soil particles obtained. In the second investigation Group B wanted to represent their results by plotting a bar graph to show the differences between the soil samples. In the third investigation they proposed plotting a line graph to illustrate the water retention properties of the different soils and in the last investigation they proposed to also draw a line graph. Although this group was creative in their ways of representing the data they obtained in their investigations, their methods of doing so were not always the most appropriate way of displaying their results. This was especially so for the last investigation where the results were not easily displayed by a line graph. In fact when these students wrote their laboratory reports for the experiments, Sven presented his results in the form of a bar graph and not a line graph. Therefore even though they proposed to use a line graph to present their results they realized that there was a more appropriate method, the bar graph, therefore Sven learnt from experience. Although Sven found difficulties in solving inquiry problems, he succeeded in identifying an appropriate way of displaying the results obtained.
4.4.2. Collecting and displaying results individually

In the individual task students also had to describe how they would record their results and how they would display them. All the students who were given the ‘hill problem’, claimed that the best way to record their results was to measure the volume of water which slid down the model on both the slope and the terraced/ altered side of the hill, in this way both sides could be compared. Many of the students also said that the best method to display their results would be in the form of a table. Since they had to display ways of decreasing water and soil loss, a table could be used to show the percentage water and soil loss in their proposed experimental set up.

On the other hand in the ‘clay soil experiment’, the students had to think of methods of increasing production in a clay soil field. Most of their methods described ways of increasing the air content in the soil by making the soil particles larger through clumping. All the students claimed that the best way of recording results would be in the form of a table and by calculating the percentage increase in air. The way they claimed they would then display their results differed as James said he would do so through a table, Dale through a diagram and Michael by plotting a bar graph. Dale’s idea of drawing a diagram in this particular experiment was not the best method of displaying his results. Overall the students were capable of thinking of ways of recording and displaying their results effectively.

4.4.3. Discussion: Were students able to think of ways of presenting and displaying their results?

In most of the investigations, groups A and C claimed they would present and display their results through the use of a table. On the other hand group B were creative in the methods they chose to present and display their results, as they planned that they would do so through either a diagram or a line graph or a bar chart. When it came to writing their laboratory reports some of the students in group B chose to either stick to
their plan or to adopt a more appropriate method to display their results. This shows that these students were constantly thinking of ways of improving their investigations and their investigation reports. In the individual tasks the way that the students claimed they would display their results depended on the type of question they were given.

Students tend to find difficulties when thinking of the right way to display their results because in recipe-type experiments they are told specifically how to record their results and which variables should be taken into consideration when a graph needs to be plotted. In the case of this study, the students were not guided as to how best to record and display their results and for this reason many chose to stick to just presenting a table of results most probably because they were unable to think of a more appropriate way.

Micallef (2010) found that students tend to find difficulties with regards to graph interpretation. The reason for this being that when teachers teach students skills related to graphs they tend to focus on “establishing a correct scale for the graph so as to make use of three quarters of the graph paper, drawing clear and neat points, obtaining a best straight line through the data points and working out the gradient” (p. 47-48). Therefore teachers tend to emphasise more on how to plot a graph properly because this is an examinable component of the SEC examination. Students would gain more if they are taught the properties of different types of graphs and how to identify the best way to display data effectively.

The following section will focus on the ‘case’ of some of the students' individual experiences throughout the inquiry process.
4.5. Individual student case studies

The following is an account of four students that present different and interesting cases.

4.5.1. Sven - The high achiever who does well in a traditional classroom which makes use of traditional tasks but finds difficulty when dealing with inquiry tasks

Sven was a high-achieving student; he was normally the one who was awarded prizes in recognition of his achievement; not just in Biology but in all three sciences. He had a very good memory and always did exceptionally well in examinations and tests. Sven was not pompous, he did not put down his class mates, and he was in fact very level headed and was normally respectful to all members of the class. Since he achieved such good grades, his friends had a very high regard of him and looked up to him, he was considered both an asset within a group and a threat to the rest of the class in terms of competition. Yet although Sven had a very good memory he was not necessarily the best when it came to problem solving and applying his knowledge.

When he worked in a group, Sven was highly respected since he was the one who always obtained the highest marks in any form of assessment. In fact in the individual interview Lee said “I mean Sven’s a genius and I am not exactly a genius. He is really good at the subject so it really helps me”, as can be seen Lee was really in awe of Sven and felt that he was inadequate in comparison to him. Yet Lee was more successful in the individual task even though he thought that Sven was better than him. According to Williams (2009), in collaborative work, “the person whose ideas are respected in general may not be the person with the best understanding of the problem to be solved” (p.7). In the case of group B, although Sven was highly respected by his peers, he was not the one who had the best problem solving skills.

Although Sven was normally a high achiever, he did not do as well when it came to problem solving skills especially when it came to working on his own. He was the only
student who did not identify the correct aim. Sven was given the “Hill problem” (refer to Appendix 6), where students had to suggest ways of improving farming on a hill and his aim was “whether water can be collected in the form of a drainage system or not.” Sven’s method proposed building a model of three hills of different steepness and then investigating which steepness loses water faster. Another method he proposed was first investigating what type of soil is found in the farmers’ field and then he suggested changing the type of soil found in the field to one which is a ‘loam soil.’ Both Sven’s methods were impractical and did not solve the problem given to the students. He did not suggest methods of improving farming land found on a hill, he just suggested water collection methods.

When Sven’s group attended the focus group, he said that he prefers group work because he says “I wouldn’t have managed on my own because everyone has their own ideas and even if we do not agree on everything we can still help each other.” He seemed very sure that he would not be able to solve the problem on his own and when the time came to actually do so, he panicked and did not succeed in solving the problem.

Sven, who was normally an academically strong student, really struggled when it came to solving a problem individually. Although this was not Sven’s first experience of PBL, it was his first experience on his own and not in a collaborative group; this could be the reason why he experienced such difficulty. Alberts (2000) claimed that if students were to experience science through an education system which stressed understanding and not just memorization, then students “with superb memorization skills, who often do well in our current science classes, will not be misled into believing that excelling in science requires the same skills as doing well on an exam” (p. 10). Therefore perhaps what we normally consider to be achievement is really the ability to remember and recall facts, when in fact it should take into consideration the ability to solve problems and apply what has been learnt to a “new” situation.

Throughout the activities and tasks I noticed that Sven felt much more comfortable within a group as he found difficulty when tackling the questions on his own. For this same reason Sven was uncomfortable in the individual task as he felt that he was incapable of solving it on his own. In the individual interview when Sven was asked whether this way of learning has helped him to understand the topic of “soil”, Sven did
not mention whether he liked IBL or PBL more than ‘normal’ lessons. He said “Yes, I learnt about water collection, air in soil, nutrients etc. Yes now I feel confident in this topic, I know it well.” As can be seen from his answer, his main focus was on the topic content and not on the inquiry process.

The students in group B (Sven, Dale, Lee and Michael) were all successful in the individual task except Sven. Since Sven was the one who normally achieved the best marks in any form of assessment, this was a very surprising outcome. According to Macdonald (2005), in the inquiry classroom the methods of assessment should display the students’ ability to apply knowledge and skills learnt to a particular context and Sven was not capable of doing so.

4.5.2. Dean- The student who is usually distracted but who managed to stay on task in the inquiry and problem based tasks.

Dean is a medium to high achiever, he was able to grasp concepts quickly and he was also distracted very easily. These qualities made him very disruptive in class especially when he was not focused on what was being done because he was bored or because he was not being challenged enough. When in a group he got frustrated very easily especially when he felt that he was doing all the work or when he was unsure about what needs to be done. Although Dean could have easily fit in with the high achievers in this class, he preferred to stay with his friends who were medium achievers; therefore the group he worked in, was truly a ‘friendship group.’

What was interesting about Dean’s progress through the case study was the fact that he was enthusiastic about the lessons and he was always on task especially throughout the investigations. Whereas normally he would drag his feet and arrive late to the lessons, during the inquiry tasks he was always punctual and ready to start the tasks, he really seemed to look forward to the lessons. I think that he appreciated the practical everyday use of the activities which were carried out since all of the activities started off with a problem which was being experienced by a farmer. According to
Ciardiello (2003), when the teacher sparks the curiosity of their student, then they will be better stimulated and motivated to learn.

During the individual task and interview, Dean solved the problem related to having a field on the side of a hill with relative ease and was also successful in identifying an appropriate method and precautions for his proposed solution. According to Hmelo-Smith (2004), “common sense suggests that to encourage students to develop flexible knowledge and effective problem-solving skills we must embed learning in contexts that require the use of these skills” (p.240). When Dean was asked about the approach he took in order to solve a problem such as the one given in the individual task he said

“Read the problem, see the differences between the two conditions, you see the problem for the farmer and how you can help him to improve his crops; you see how you can fix it and then you see how your ideas would improve production. After you see how you can test it.”

Dean had a good strategy for problem solving, the context of the farmer asking for advice placed learning within a context for Dean and this encouraged him to solve the problem given. According to Edens (2000), PBL is most effective when “learning is anchored to real-world or authentic contexts- students learn how to apply inert knowledge to real problems” (p. 55).

Following the task, Dean claimed that he liked learning about soil in this way because he said:

“You can see what is happening (topic content) hands on. You see different soils and then you think how their properties would affect the plant and why. For example for certain plants it is better to use a particular soil because it grows better.”

This more practical problem based method of learning really brought out a side to Dean which I as his teacher for over a year had never seen before. According to Alouf and Bentley (2003), some teachers fear that behaviour would worsen when using the inquiry approach to teaching, yet in my case students who were usually disruptive and restless in the traditional classroom were actually very focused and on task during the inquiry activities.
4.5.3. Michael- The high achiever who really enjoyed the inquiry based lessons

Michael was a high achiever who was at times difficult to work with but was very good friends with Lee. Unfortunately the other members of the class made fun of Michael by calling him a nerd. He was often the victim and he was easily offended. He was normally a very well behaved and hardworking student. Prior to the study Michael was one of those students who did not enjoy activities but who just wanted to cover topic content saying things like “Do we need to study this for the SEC examination?”

Yet I was surprised at how much he enjoyed the inquiry activities, in fact following the first investigation activity, Michael stayed behind after the bell rang for break and I asked him how he felt that today’s session went. He told me:

“I preferred today’s lab session much more than usual because I understood what we were doing and why we were doing it, normally we just follow the instructions and we do not think about what we are doing. Can we learn about other topics in this way?”

After hearing this I started to wonder whether I would be able to teach other topics through inquiry since if it is well thought out, it is clearly a more effective approach.

Michael was not only successful within a collaborative group but also in the individual task. In fact when given task 2 (refer to Appendix 6), was immediately able to think of a viable method of improving the soil as he suggested adding humus to the soil which creates larger soil crumbs which as a result would increase the amount of air in the soil and improve soil permeability. His method included a control which would be the untreated clay soil and his experiment included adding humus to the clay soil and mixing it. He then applied the method his group had used in order to find water permeability in soil in order to test the water drainage properties of the untreated and treated soil samples. Apart from choosing a suitable method in order to test his hypothesis, Michael was also capable of thinking of a suitable method to record his results: in the form of a table and a suitable way of displaying them: in the form of a bar graph. He was also able to identify precautions to decrease the sources of error in his planned investigation.
Therefore one could say that Michael succeeded fully when it came to the individual task. During the interview he was asked to rate the task which he carried out and he claimed that it was of moderate difficulty and when asked to give a reason he said:

“Because it wasn’t that clear, it could be because I am not that good in this subject … I mean when you have the concept you can then apply it to the problem at hand, ideas start coming to you. But until you get the concept it is not easy.”

This echoes the words of Chin and Chia (2005) who claimed that in PBL, “students work on a problem that is situated in real-life contexts, they are better able to construct links between school science and the science required to solve real-world problems” (p. 46). Therefore through PBL, students are better able to identify the information they need in order to solve a problem which is in a real-life context.

Michael was one of the few students who in the individual interview said that the skills tasks were essential to solving the problems which were given at a later stage. He claimed that “the skills tasks before the experiments helped us because they made us think: How are you going to interpret the results? How are you going to conclude? They helped us to do these things.” Therefore he was able to make a link between the skills tasks which were carried out previously and the investigative tasks which were done in the laboratory. Other students could not explain why the tasks helped them, some even claimed that they had forgotten what was done yet at the same time they felt that the tasks helped them subconsciously.

Michael also claimed that he really enjoyed this problem first approach to learning about soil, he said:

“Problem solving investigations give you an idea about what you’re going to study and then everything becomes very clear, they are very good. You know how to test for it, you reason things out, for example we concluded clay soil keeps a lot of water, and through the investigations we learnt the properties of the soil.”

Whereas in a traditional classroom, the students are given all the information before conducting the investigations, in IBL, they use the information which they gather from their investigations in order to piece together their knowledge about a particular topic. In the case of this study, they used their data in order to learn about properties of different soils. Greenwald (2000) claims that through PBL, the order of learning is “inverted to reflect real life-learning and problem solving. Learning begins after students are confronted with an ill-defined problem” (p.28).
4.5.4. Jake- The student who struggles both in a ‘traditional classroom’ setting and also in an inquiry based learning setting

Jake was a low to average achiever; he did not study much and did not put an effort in his work. He did not seem to care about how he does in the subject. From my observations, this was a mask he wore in class, in reality he was very insecure and did not believe in himself. Since he felt that he was ‘not good enough’, he adopted an ‘I don’t care attitude’, this attitude was picked up by the other students in the class. In the focus group, Dean said that he would not like to work with Jake or the students in Group A “because I think they would make me do all the work.” He claimed that Jake has an ‘anything goes’ attitude which would result in him (Dean) doing all the work.

In the first laboratory session, Jake lived up to his reputation of not doing much in class except follow what Martin told him to do. Yet in the second session there was a role reversal, as the group decided to follow the suggestions given by Jake. The fact that the group chose to carry out Jake’s method really boosted his confidence and helped him to work successfully with his group mates. At the end of the session Jake made it a point to come up to me “Miss, do you know that today we did what I wanted to do? It isn’t normal for me to tell the others what to do!” I then asked him “how did that make you feel?” and he said “for once I felt intelligent and proud of being the one to come up with the idea” Therefore inquiry based learning, allowed Jake to experience success, success which he had not experienced before in Biology.

Jake found difficulties in solving the individual task; he was given Problem B. Jake was able to identify the need for the farmer to introduce a rubble wall yet he could not think of an appropriate laboratory experiment to test his prediction. In fact his suggested method was to use the filtration set-up which did not take into consideration the slope of the hill or even the rubble wall. He only mentioned the ‘barrier of rocks’ later on, in the ‘variable’ section, yet he did not specify how he would do so. When asked to identify what needs to be measured in this experiment he said “water and soil loss” which was correct.

Jake was not successful in identifying an appropriate method to test his prediction; but he was successful in applying his content knowledge to the problem given and this
was evident in his prediction. When he was asked to give the main steps he took to solve the problem he said:

“First you read it and then you picture the situation in your mind and then you start thinking about how to solve the problem at hand. The fact that we did an experiment which was similar it was easier to apply what we had done.”

His words show that he thought the solution to this problem was similar to that of investigation 3 even though that was not the case.

In end of topic tests in the past, Jake did not do very well; obtaining marks which rarely exceeded the 50/100 pass mark. After the topic of ‘Soil and Agriculture’ the students were given an end of topic test which assessed their topic content knowledge, Jake obtained a 35% in this test. When I gave him back his test he told me “Miss, I did not study for this test”. Even though the topic was covered through an inquiry based approach, it was still important for the students to study their topic notes well; if they did not study they did not achieve a good mark in traditional methods of assessment. Although Jake failed the end of topic test and did not succeed in the individual task, I chose to reflect on his particular case because I felt that at least in one of the investigations he had an opportunity to experience success and to be proud of himself because he had ownership over his learning and he contributed to his group. Jake may have failed in the content part of the topic which was related to types and proportions of soil but he learnt other skills that were not assess by the end of topic test.

4.6. Conclusion to the inquiry skills section

The students’ work in the planning stage of the investigative tasks and my observations of the students both while they were working as a group and carrying out the investigations, allowed me as the researcher to better understand their ability to utilize their inquiry skills and conduct their planned investigations in the laboratory. Through these different sources of information I could obtain a clearer understanding
about whether they could solve the problem as a group collaboratively and later on, on their own through an individual task.

From the data gathered, conclusions were reached about the students’ individual ability to solve the problem given to them. The students in group A were Martin, James and Jake. Unfortunately following the focus group interview Martin did not participate in the individual interview or the inquiry skills task which was done later on, therefore the only data with regards to Martin is his performance in the end of unit test on the topic of soil. Since Martin was the one who led the group work in the investigative tasks, it was interesting to observe whether James and Jake would successfully complete the individual tasks or not without his help. In fact both James and Jake struggled in certain parts of the individual task and this showed how beneficial it was for both of them to be grouped with Martin in the collaborative tasks.

The students in group B were Sven, Dale, Lee and Michael; all the students in this group were successful in the individual task except Sven. Since Sven was the one who normally achieved the best marks in any form of assessment, this was a very surprising outcome.

The students in group C were Dean, Ben, and Steven who were average ability students yet they all succeeded in completing the individual task. Although some members were more dominant in the collaborative tasks, their performance in the individual task showed that they were very capable even when they were alone.

The students were also given an ‘inquiry test’ six months after the inquiry skills lessons. The aim of the test was to comprehend whether the students retained the knowledge they gained through the inquiry skills lessons and investigations. The test also served to identify whether the inquiry skills learning outcomes which were set prior to the lessons were reached by the students.
4.7. Six months later…the inquiry skills task

Prior to the case-study, a set of inquiry skills learning outcomes were identified. The student then carried out the tasks both in collaborative groups and also individually; these tasks required them to apply the previously learnt skills to the tasks they were carrying out. Yet it was also important to understand whether the students retained the skills which they learnt. Therefore to comprehend whether this happened or not the students were given an ‘inquiry skills task’ (six months after the initial tasks), which focused on the skills which were identified in the learning outcomes. The students were not told that it was a test and the word ‘task’ was used instead yet they were also told that they had to work individually and not talk during the activity. The task which was given to the students can be viewed in Appendix 9, the task was adapted from the Royal Society of Chemistry (2005). The students were given a situation which can briefly be described as: When certain fruit is added to jelly, it does not always set, yet when the tinned version of the fruit is added, the jelly sets. The students then had to answer a number of questions related to the task.

4.7.1. The learning outcomes

The learning outcomes which were chosen prior to the study in relation to inquiry skills were:

- State scientific questions related to a situation or problem.
- Identify what makes a question ‘scientific’.
- Write a testable prediction.
- Think of a suitable method to test their prediction.
- Differentiate between an experimental and a fixed variable.
- Differentiate between an independent and dependent variable.
- Describe what makes a ‘fair test’.
- Measure and collect results from an experiment.
- Interpret results.
- Display results in an appropriate manner.

Although these learning outcomes were identified, it was difficult to assess the students’ ability in all the skills through one task, especially since the task was completed in a classroom and not in a laboratory. The learning outcomes which were investigated through this task were:

- State scientific questions related to a situation or problem.
- Identify what makes a question ‘scientific’.
- Write a testable prediction.
- Select the right method to test a prediction.
- Differentiate between an experimental and a fixed variable.
- Differentiate between an independent and dependent variable.
- Display results in an appropriate manner.

4.7.2. Students performance in the inquiry task- ability to think of scientific questions related to a situation or problem.

All the students were capable of asking at least one scientific question related to the problem. The differences between the students were the number and type of questions which they asked. Lee was the most successful in thinking of different scientific questions, in fact he thought of four different scientific questions which were: “What happens in the tinning process?”, “Why is the fruit heated before it is tinned?”, “Which enzyme do fruit contain?” and “What is the difference between fresh and tinned fruit?”. The most prevalent question asked by the students (six out of nine students), was “What is the difference between fresh and tinned fruit?” and this was the most important question which they should have been asking in this task. Only one student asked a question which did not appear to be scientific in nature, James asked “would the colour of the jelly make a difference?”
4.7.3. Students performance in the inquiry task- Ability to identify what makes a question ‘scientific’:

Although this was not really a skill, it was interesting to understand the students’ perceptions of what a scientific question was and what makes a question scientific since one of the science skills activities was focused on this topic. Some misconceptions about this topic were still prevalent among the students in fact only five out of nine students were capable of pin-pointing factors which make questions scientific. Some of the answers given by students were:

Liam said “You have to conduct an experiment to prove or disprove the hypothesis.”

Jake said “Scientific questions should be proven scientifically and tested.”

Sven said “These are questions which could be proven by testing”.

Dale: “These are questions which could be proven scientifically and could be tested”

On the other hand some students still believe the following about scientific questioning:

James: “Questions about the subject. They have biological keywords in the question.”

Liam said “You have to prove the hypothesis using scientific questions”

Dean: “Technical words and facts”

Jake: “Scientific words for example temperature and concentration”

Ben: “Using scientific words and asking questions involving the Biology of the subject.”

As can be seen from the answers given by the students, some have a clear idea of what makes a question scientific, in that it is a testable question which is used to build an investigation and can be used to prove or disprove a hypothesis. Other students refer to a scientific question as being one which involves “technical or scientific words”
and they do not link scientific questions with any form of investigation. What was interesting was the fact that the students did not link questioning with inquiry, which was defined by Martin- Hansen (2002) as being “the activities of students such as posing questions, planning investigations, and reviewing what is already known in light of experimental evidence that mirror what scientists do” (p.35). Even though these students experienced various forms of inquiry, they still saw scientific questions as being a type of question which has a particular vocabulary; they did not link it with solving problems.

4.7.4. Students performance in the inquiry task-writing a testable hypothesis.

The students then had to think of a hypothesis for the task which they were solving. In the inquiry skills lessons the conclusion which was drawn about how to write a proper hypothesis was that it should be in the format of and “If… then…. statement”. The number of students, who followed this format in this task, was seven out of nine students. Some examples of appropriately worded hypotheses were:

Steven: “If the fruit is boiled the enzymes will be denatured and so the jelly will set.”

Michael: “Gelatine with fresh fruit will not set, but if the fruit is heated no enzymes will break down the gelatine”

Lee: “If fresh fruit is used, the jelly will not set. If tinned fruit is used it will set.”

Dale: “If the temperature increases then the enzymes would be denatured and the jelly would set.”

On the other hand some students were clearly unsure about how to word a proper hypothesis, for example:

Dean: “Enzymes will denature the jelly.”

Jake: “If the temperature increases then the enzymes would be denatured.”
4.7.5. *Students performance in the inquiry task- selecting the right method to test their hypothesis.*

All the students except Dean were capable of describing a method, which they could use in order to test their hypothesis.

4.7.6. *Students performance in the inquiry task- differentiating between an experimental and a fixed variable.*

When it came to identifying the different types of variables, students always experienced difficulties through the tasks in the study. The first variable related task which they had to complete was identifying the experimental and fixed variables. Most of the students (eight out of nine) were capable of identifying both the experimental and fixed variables. The only student who experienced difficulties was James; he was only capable of identifying one fixed variable “same size of pieces of fruit.” Some examples of work given by students who were successful are:

Steven:

Fixed variables: “same amount of fruit”, “time for jelly to set should be the same”. Experimental variables: “Whether the fruit is boiled or fresh”.

Lee:

Fixed variables: “Size of fruit”, “Volume of jelly” and “Brand of jelly”. Experimental variable: “Whether the fruit is heated or not.”
4.7.7. Students performance in the inquiry task- differentiating between an independent and dependent variable

This was the second variable related task were students had to identify independent and dependent variables. Students found this task more difficult in fact only five out of nine students were capable of identifying the right variables. The students who were not successful in this task mixed the type of variable, these students were Steven, Dean, Michael and Ben.

An example of a student who identified the variables correctly:

Jake:

Independent variable: time and type of fruit, and the dependent variable: Whether the jelly sets or not.

An example of a student who identified the variables incorrectly:

Ben:

Independent variable: Whether the jelly sets or not and the dependent variable: Time, temperature, pH levels and freshness of fruit.

4.7.8. Students performance in the inquiry task- recording and displaying results in an appropriate manner.

The last thing students had to do was plan how they would firstly record the results and also how they would display their results. The results which they should have recorded for this experiment were whether the jelly sets or not. Yet only one student, Lee, referred to this particular observation. All the others said that they would record their result in table form after taking observations. Some students (three out of nine)
said that they would display their results using pictures. One student (Dale) said that he would display his results using a graph and this was not an appropriate method of doing so for this particular experiment.

4.7.9. Conclusion

Overall it can be concluded that the skills obtained through the inquiry skills lessons and the investigations and tasks which followed, were retained by the students who participated in the study. Most students were successful in completing the task which was given to them six months after the case study took place.

4.8. Learning and understanding the topic of soil

Learning and applying inquiry skills both individually and collaboratively were the main areas in this study yet these were taught through the backdrop of the topic of “Soil and agriculture”. Since this topic was taught through inquiry based pedagogy, it was important for me to understand whether the students also learnt the topic content and not just the inquiry skills. After the study took place, the students were given notes which would aid them in their studies. These notes consisted of a summary of the points which had emerged from the investigations, the properties of different soil types and how this knowledge can be applied to improve agricultural practices. In the focus group, Ben had pointed out that he felt insecure about the content covered through the activities he said “I feel that through these activities, you are never too sure about whether you are doing it right or not” he then went on to say “you did not tell us if we were correct or not, you just discussed our method with us.” Ben’s feeling of insecurity echoed those of the students in Edens (2000) study who said “we had no idea if we were on the right track” (p.59). Therefore by providing them with notes, the students were more confident about what they were required to study for the SEC examination.
Following the completion of any topic the students would normally be given a test which would assess their content knowledge. The same was done for the topic of soil and agriculture, the test assessed students on some of the learning objectives which were identified prior to the study and which took into consideration the SEC syllabus. The types of questions given to the students were similar in nature to those found in examinations.

The following are all of the learning objectives for the topic which were identified prior to the study.

- Describe the origin of soil.
- List the components found in soil.
- List the main types of soil.
- Discuss the properties of the different types of soils (Size of particles. Do they retain water or do they drain easily? Do they contain a lot of air?)
- Describe an experiment to investigate humus content in soil.
- Describe an experiment to investigate water content in soil.
- Describe an experiment to investigate air content in soil.
- Describe the water retention or drainage of various soils.
- List and discuss the various biotic and abiotic soil components.
- Describe soil as an ecosystem in itself.
- Describe various organisms which live in soil.
- Describe the beneficial/harmful effect of soil organisms on the soil.
- Apply what has been learnt about soil properties to issues experienced in agriculture. (For example how to decrease soil erosion, how to change the pH of soil and how to decrease the depletion of nutrients in the soil.)
- Explain how contour ploughing, strip cropping, crop rotation and terracing can be used in order to decrease soil erosion and nutrient depletion
- Explain the advantages of using natural fertilizer and natural pesticides or biological control instead of chemicals which can remain in the ecosystem.

As in any other topic tests or examinations, it was difficult to assess students on the
entire topic learning outcomes. The learning outcomes which were assessed in this test were:

- Describe the origin of soil.
- List the main types of soil.
- Discuss the properties of the different types of soils (Size of particles. Do they retain water or do they drain easily? Do they contain a lot of air?)
- Describe an experiment to investigate water content in soil.
- Describe an experiment investigate the water retention or drainage of various soils.
- Identify various organisms which live in soil.
- Describe the beneficial/harmful effect of soil organisms on the soil.
- Explain how contour ploughing, strip cropping, crop rotation and terracing can be used in order to decrease soil erosion and nutrient depletion

4.8.1. Student achievement in topic test

The topic was taught mostly through inquiry based pedagogy, a pedagogy which was very different from the more traditional approach students were accustomed to. Overall the students did very well in the end of topic test, in fact only one student failed and all the others achieved a mark over 60%, the highest mark being 95%.

Prior to the study the students had carried out another test which was about a different topic and therefore comparing the students’ success in the test of soil to that of the previous topic could only be a superficial means of comparison. Yet after comparing the students’ mark in the test on the topic of soil with the other test, a number of interesting points arose. Seven out of ten students managed to achieve a higher score in the test on soil and agriculture when compared to their previous test results. Three students (Dale, Lee and Martin) obtained a slightly lower mark in the test on soil and agriculture yet still obtained marks which exceeded 70%. Three students (Ben, James and Steven) who had failed in the previous test, managed to obtain a mark between 65%-72% in the test related to soil. Unfortunately one student did not succeed in
passing this test, Jake obtained a mark of 35%, a similar mark to that obtained in the previous test (34%). Yet after receiving his test paper, he told me “Miss, I did not study, that is why I got that mark”. Although the students were taught using an inquiry based pedagogy, it was still important for them to revise in order to gain content knowledge in order to answer the knowledge related questions asked in the test.

From the results obtained, one can conclude that the students in this study achieved a good result in the test related to the topic of ‘Soil and Agriculture’. There has been little research about the acquisition of knowledge through IBL in secondary school students, yet Hmelo-Smith (2004) claimed that overall students who were taught using PBL achieved better results than those in a traditional class. Hmelo-Smith cited the work of Dods (1997) whose research was with gifted secondary school students. Dods claimed that “students tended to retain information presented in PBL units better than information from traditional units, despite the fact that the students thought they learned more in lecture-based units” (p.252). Hmelo-Smith also cited the work of Gallagher and Stepien (1996) whose research was also with gifted secondary school students, they found that “The PBL students scored higher on a multiple-choice test than traditionally instructed students” (p. 252).

Similar results were obtained by the research of Geier, Blumenfeld, Marx, Krajcik, Fishman, Soloway & Clay-Chambers (2008), whose study showed that students taught using a IBL pedagogy achieved significantly higher grades than those taught the same units a traditional classroom. Yet Geier et al. also claimed that “students, too, must adapt to new expectations and teaching styles” (p. 934) therefore although the overall effect was an improvement in student achievement, the students also were expected to make an effort in order to succeed within an IBL classroom. The results in this study indicated that students through IBL not only did students gain inquiry skills but they also gained subject knowledge which was fundamental to their success in the SEC level examinations they were to sit for. The only student who failed to pass in the end of topic test clearly did not put in the revision work which was fundamental to his success in the test.
4.9. Conclusion to the chapter

From the results obtained one can conclude that most students were able to apply the previously taught inquiry skills to the investigative problem both in groups and individually. Students were more successful when they worked in collaborative groups compared to when they worked on a problem individually. A few students struggled in the individual task as they found applying the inquiry skills taught to the problem difficult especially when they were on their own and not in a collaborative group.

Not only were most of the students successful in the inquiry tasks but most also did well in an end of topic test which focused on whether students learnt topic content or not. Students were also able to apply the inquiry skills six months after the inquiry skills lessons. The next chapter will focus on the collaborative groups formed and whether the students collaborated successfully or not.
Chapter 5

Results and Discussion: Collaborative work
5.0. Introduction

This chapter will firstly present the different student groups formed in the study. Then the focus will be on the reasons why students chose to work with the other members of their group. The chapter will then discuss the first research question which was: “To what extent do fifteen year old Biology students work collaboratively when dealing with inquiry tasks?”

5.1. Grouping Students

5.1.1. Group formation

Although the school was a mixed ability school, the students in this Biology class were either low-average achievers (obtaining marks between 40-60% in examinations) or above average achievers (60-70% in examinations) or high achievers (80-90% in examinations). These students had been in the same Biology class since the age of 14 (Form 4) and they were at the time of the study between 15-16 years of age (Form 5). Most of the students attended the same school since they were 3 years of age and therefore were very familiar with each other.

The students were given the opportunity to work with whom they wished for the skill lesson: ‘Group work.’ Students immediately decided to work with their friends or people they felt comfortable with. The groups which resulted were friendship groups, some of these groups were also homogenous in terms of achievement.
5.1.2. *My observations of the groups which formed*

The groups were formed on the first day of the skills lessons. In this first lesson, the focus was on ‘Working in groups’. In this lesson I asked students to reflect on what best to do whilst working in a group. Following this skill lesson, the students then had to work with the same group for the rest of the topic.

The students in this study were allowed to work with whomever they wished, their success depended solely on the work they put into the task as a team. According to Pauli, Mohiyeddini, Bray, Michie & Street (2008), “there is evidence that instructors appear to get the blame if group work goes wrong, but little acknowledgement if it is successful” (p.48). An example of this is when students blame their lack of success on the teachers’ methods of grouping students. Since the students in this study chose their own group, they had to be responsible for their groups’ success. It was interesting to note the different groups which formed when the students were asked to form groups of 3 or 4 students.

Group A, was made up of three students, two of whom do not normally do well in tests and another student who obtains average marks in tests.

Group B was made up of two pairs of high achievers; I say pairs because they normally work in pairs, so they teamed up together. Generally this group of four does not work together but when asked to group up in either groups of 3 or 4, they instantly decided to work together. It was clear to me that they only did so since they felt that the other pair is their equal in terms of ability since all these students obtain marks over 80% in tests and examinations. In fact in Michaels’ individual interview he said “I felt very good in this group because they are intelligent like me (not as much though) and I can share my opinions and be reassured”. On the other hand Dale said he chose to work with Sven because he is his friend but he only worked with Michael and Lee as “obviously, the good students stay with the good students.” Therefore the choice of these two pairs to work together was due to their academic achievement and not because of friendship.

Group C was made up of three good friends who are similar in ability, one student being slightly higher in ability when compared to his friends.
Since I had decided to allow students to work with their friends, I was worried about the groups which resulted. My main concerns were that the largest group which was composed of four high ability students would succeed in solving the problem solving tasks whilst the other student groups would not succeed. I did not wish my students to experience failure through IBL yet at the same time I did not want to tell them that the groups they formed themselves were ‘not good enough’. These thoughts were a result of me not believing in my students’ abilities and communication skills.

From my observations I concluded that when allowed to work with whom they wished, these students either chose to work with their friends, or with people who they have worked well with in the past. When students were not chosen by others to be in their group they worked with whoever was left over after the other groups were formed, from my observations, group A seemed to have been formed in this way.

5.1.3. Why did students’ decide to work with the people in their group?

When students were asked individually during the individual interview why they chose to work with the people in their group, their answers varied according to the group.

Two of the students from group A, who attended the individual interview, were James and Jake, both students who were low-achievers. James said that he chose to work with his friends because according to him, friends “help each other, understand each other and listen to each other.” Jake claimed that his group: “did not do everything by themselves, they respected me and valued my input to the task. They did not take over and ignore me.” There are clear emotional benefits when working with friends since they allow students to feel comfortable. It is interesting to note that students who were low achievers had a tendency of feeling left out when they are not placed in groups chosen by them. Since they feel left out, this leaves them feeling alone within a group, where in theory everyone should feel included.
When the students of group B were asked why they chose to work with the people in their group their answers varied. Sven, who normally stays with Dale, said that he chose to work with him because he said “I know him well and I feel comfortable with him, he is very good in the subject.” I then asked him why he chose to work with Lee and Michael and his answer was “because they are intelligent and they know what to do in the subject and they can help me.”

Shachar (2003) claimed that high achievers dislike collaborative work because they “were unwilling to do the work for the other members of the group whose grades were lower than theirs” (p.104). From Sven’s response it is clear that he wants to be in a group where he can seek help. Therefore even higher achieving students want to be grouped with peers who can help them; they do not like the group depending on them for information. In fact when asked whether he could have done more, Sven said that at times he held back “because they always think I am right and I wanted them to think and come up with their own ideas and not just follow what I say.” Although Sven was in a high achieving group he did not wish for his group to depend on him for all the ideas and information.

On the other hand Dale chose to work with Sven because they are good friends but when questioned about Michael and Lee, it became clear that he only chose to work with them for the simple reason that they are good in the subject. In fact when I asked him directly about this he said “obviously because the good students work with the good students!” According to Dillenbourg (1999), for collaborative work to be successful, peers should be “more or less at the same level, can perform the same actions, have a common goal and work together” (p.7). Therefore this could be the reason why this student chose to work with students of a similar ability, to ensure homogeneity of knowledge and better productivity.

Lee, the third member of this group decided to work with his group for a similar reason to Sven’s: “I know that if I need help they can help me. I could also help them even if I was not exactly on their level (intelligence), so like this we could help each other and reach a middle point.” Learning how to resolve issues amicably is something students learn in collaborative learning. According to Lord (2001), “Students learn how to challenge ideas and advocate for their positions without personalizing their
statements. They also learn conflict resolution methods that are important for real life situations” (p.34).

When questioned further about what he meant about ‘level’, Lee said “I mean Sven’s a genius and I am not exactly a genius. He is really good at the subject so it really helps me.” From these responses it is clear that higher ability students seek out other high ability students because they would like someone in the group to be able to help them. The undertone to what Lee said was that although he himself is good, he is not as good as Sven and when he is able to help Sven this really makes him feel good about himself. Michael who was also part of this group claimed that he felt very comfortable in this group “because they are intelligent and they are friends so I feel more confident and comfortable with them.”

All four participants of this group wished to be placed with students of a similar ability to their own since they are all high-achievers. Lou et al. (1996) claimed that it is unethical to delay the achievement of high-ability students by placing them in heterogeneous groups. This is because they might spend their time instructing other group members instead of learning new information from the activity. Therefore allowing these students to work with others of a similar ability, enhanced the learning process since they spent more time on task rather than explaining to students of a lower ability. By working with students of a similar ability, one may also clarify their own concepts and get a better understanding when explaining to others.

On the other hand studies have suggested that heterogeneous grouping is also beneficial to students, since according to Oakley, Felder, Brent, & Elhajj (2004) in “well-functioning diverse groups, the weak students get the benefit of seeing how good students approach assignments and they may also get some individual tutoring, while the strong students who do the tutoring may benefit even more” (p.11). Yet this is only the case in ‘well-functioning groups’ since more often than not higher achieving students tend to take over and students of a lower ability are more often than not ignored since their opinion is not respected as much as that of their higher achieving peers. In this study the fact that students of a lower achievement level chose to work together, only served to boost their confidence and this gave them an opportunity to be heard and feel valued.
Group C was made up of three friends who were similar in ability. When Dean was asked why he chose to work with his group, his answer was “I feel confident with them, because I know them not just from school. I did not feel alone, I am sure that if I have a problem I can talk to Ben or Steven and they will help me if they can. I can also help them in this way and they feel comfortable with me too.” In this case Dean’s familiarity with his group served to help him to feel comfortable with them and also to ensure that they will not make fun of him but will try to help him in any way they can.

Ben, also a member of the same group said that within this group: “I felt good, because we went through tasks well and we could understand each other. We also helped each other.” For Ben like Dean, being able to help and understand each other was an important factor in this group’s success. Steven chose his group because they are his friends, are similar in achievement level and they are nice to him. It seems that all students irrespective of level of achievement want to feel comfortable, find help and support and also want to be able to contribute to the group work.

5.1.4. How students would have felt had they been in a different group

When the students of group A were asked how they would have felt in a different group, James and Jake said that he would not have wished to be in another group according to Jake the reason being “because they wouldn’t have let me share my ideas on how to do a task. They would have ignored me.” Both students did not wish to be grouped with a high achieving student since they would have been ignored or not given a say in the way the group went about an activity. Within a friendship group these students were given the opportunity to be responsible for their learning and to voice their opinion; privileges they may not have experienced if a high achieving student was in their group.

All the students in group B claimed that they would have felt uncomfortable in another group. Sven said: “the other groups would not respect me and would make fun of me.” Both Michael and Sven shared the same fear of ‘being picked on’ by other students,
this could be because of past group work experiences. Although Michael chose to
work with his group because of their intelligence, he was the only student who said
that if he were in a different group he would have contributed more “they are less
intelligent and as long as they don’t pick on me, I could help them.”

On the other hand Dale claimed “I would have worked less (in another group) because
we would have joked and wasted time.” Similarly, Lee said that he did not feel that he
would not have fit in with any other group: “I wouldn’t have felt comfortable because
they don’t work. The people in my group were very diligent, they always do their work.
They do not waste time and are hard working.” Dale and Lee probably perceive low-
achievers in this way because they are not hard working and are less motivated. The
high achievers know this and associate low achiever groups with joking and wasting
time.

The students in group C also would not have been comfortable had they been in any
other group. Dean claimed that had he been in the higher ability group he would not
have felt comfortable, he said: “not because I am not capable or would not have kept
up with them but because I am sure that Sven or Dale would always want things their
way and would not have let me try my own methods.” On the other hand if he were in
group A he would not have felt comfortable because he said: “I would have ended up
doing everything myself, they would have depended on me, Jake is too laid back and
they wouldn’t have helped.”

Steven also would not have been happy in another group because he felt that he would
not have been given the opportunity to do as much as he did in his group he said:
“some people, who think that they are smart, do not let other people think or do
anything. Then there are other people who let you do all the work and they do nothing
themselves.” Ben who was also in this group claimed that had he been in a different
group (higher in achievement level), the group might have produced better work yet
this would have been because of the other students and not because he would have
worked more. On the other hand if he were in a group of lower achievement, he
claimed “I would have probably done more but I don’t think I would have achieved a
better mark.”

Being ignored and not being given a chance to contribute to activities were concerns
shared by all these students. Pauli et al. (2008), claimed that differences in status
between group members can lead to members of a higher status taking over the group activity and members of a low status being given less opportunities to interact and influence the choices of the group. As a result “This may lead to learned helplessness and self-perceived incompetence in low status group members as a result of their efforts being rejected by the higher status members” (p.48). Noddings (1989) as cited by Lou et al. (1996), claimed that when the task is academic and the groups are heterogeneously formed, the group members tend to look to the more able students for help and they depend on them for answers.

Lou et al. (1996) and Gillies (2003) claimed that groups should be heterogeneous or mixed ability since this is beneficial to lower ability students, as stated by Ben. The problem in this situation is: does heterogeneous grouping benefit high ability students or are they just there purely to aid in the learning process. One cannot help but wonder how heterogeneous grouping benefits the low achieving students; do they benefit because their success was measured in marks obtained for the group activity or because they had truly understood the concepts learned? From the response given by Ben, very often the group would achieve a better mark only because of the effort of the high achieving students.

Students of similar achievement levels chose to work together as they felt they would be more respected and included within their respective groups. By being with students of similar achievement levels, all the members of the group had to pull their own weight since their groups’ success depended on it.

5.2. Did the students succeed in collaborating with their peers?

Prior to the study I expected most of my students to collaborate well with their group but at the same time I anticipated that a few individuals would be disruptive and slow down the learning process. The following sections will discuss each group’s progress throughout the investigative tasks.
5.2.1. Student group A

In the first investigation, group A was not collaborative at all, whereas the other groups were reading the task as a group (for example one person was reading and the others listening), this group did not even bother reading the problem together. Martin was clearly the one who was doing all the thinking, he was the first to read the problem on his own and he immediately started planning. Jake was doing something else at the beginning of the task and he was just depending on the others to solve the problem presented to them. James read the question but he did not come up with his own plan, he just relied on Martin for the answers. As a group they agreed on following Martin’s plan and then started filling in the planning sheet and then carried out the experiment as he instructed. While I was moving around the class to observe and aid the students in their work, Martin kept pointing out the fact that he was the only one who was working properly and the rest of his group were either ‘doing nothing’ or ‘doing as he said.’

Pauli, Mohiyeddini, Bray, Michie & Street (2008), discussed difficulties experienced by students during collaborative work. They found that students normally object to group work because there is a “potential for conflict between group members, and the possibility of individual group members not doing their share of the work” (p.48). Another factor which worries students is that the group work will have a negative effect on their overall grade. Pauli et al. (2008) also claimed that students who fail to engage with the task at hand tend to cause problems within the group.

One of the main problems described by Pauli et al. were “social loafing”, “free loading” or “free riding” (p.48). This occurred “when one or more students fail to contribute to the group effort because they assume that the work will be done by more talented or more motivated group members” (p.48). In a situation where some students are not contributing to the work, the other students normally get upset and this leads to two situations. According to Pauli et al., it can either lead to one or two group members taking full responsibility of all the work the group should be doing and as a result becoming as Pauli et al. put it the “sucker” of the group, or it could lead to motivated and competent students withdrawing “from the group effort because they perceive others as not contributing to the same level as themselves” (p.48).
Wang and Burton (2010), claim that “the free-rider effect may eventually let a collaborative learning activity go against its purpose- participating and learning for all group members” (p. 1).

In the case of group A, Martin was the “sucker” of the group as he was the one who ended up doing all the work on the first day of investigations. Yet this was probably because at the beginning of the investigation, I had overheard Martin saying that he had already done this topic during private lessons and for this reason he knew exactly what they should be doing. The following is an excerpt of their conversation:

Martin: “I already did this at private lessons, all we have to do is add water to the soil, mix it and then allow it to settle.”

Jake: “If you know what to do then we will follow what you say.”

James: “Are you sure this method is correct?”

Martin: “Yes….yes I remember exactly what to do”.

Martin may have felt like the other group members were not doing their part but he did not even give them time to think of how to solve the problem; he just gave them the solution. Although Martin was the one who dominated how to carry out the task, each member in the group had his own role. For example at the end of the experiment when it was time to clear up, this was James’s job within the group. James he did not try to voice his opinions or methods of solving the problem, for this reason he was given an inferior job to carry out. In fact I overheard Martin tell him: “Why don’t you wash the apparatus James? You did nothing else today… you should do something.” On the other hand Jake helped Martin to carry out the experiment but he also got away with doing nothing most of the time since he was also depending on Martin for instructions.

On the second day of the investigations some changes occurred, whilst James was cleaning up the soil from their previous experiment, Jake and Martin started reading the problem which they would be covering today. They read the problem and seemed to have already started formulating a plan when James came back. I then gave them time to go through their plan and then joined them to see how they were going to solve the problem. Jake, who was normally the one who let others members of the group do
all the work, came up with a method by himself. This is a snippet of their thinking process:

Jake: “I think we should put the soil in a filter funnel and then the water goes through it”.

James: “But if we do that won’t the soil go down with it?”

Martin: “In the filter funnel we can put filter paper like we do in chemistry!”

Jake: “Yes that should work because the small particles will get stuck in the filter paper.”

Martin: “But what will we measure?”

James: “The farmer wants a soil which does not dry too quickly or too slowly. So I think we have to measure time to see how fast water passes through the soil.”

Jake: “Ok so we need a stop watch”.

As could be seen from the above conversation, all the students felt comfortable asking each other for clarification, they were building on each other’s ideas and this was a sign of real collaboration. There was a clear role reversal, whereas in the previous investigation it was Martin who came up with the ideas and the others just followed him, in the second investigation Jake was the one who came up with the method. Since Jake was working hard, his group mates were not frustrated with him and as a result they worked much more efficiently. James who was also not very helpful last time also contributed a lot of useful information to the group and as a result they carried out the task without arguing as no one was frustrated because some members of the group were doing nothing. Normally Jake was not very helpful and contributed very little, yet the fact that the group chose to carry out his method really boosted his confidence and helped him to work successfully with his group mates. At the end Jake made it a point to come up to me and say “Miss you know that today we did what I wanted to do? It isn’t normal for me to tell the others what to do” I replied: “How did that make you feel?” and Jake said: “for once I felt intelligent and I feel proud of being the one to come up with the idea.”
On the third day of the investigations James was the one who came up with the idea of heating. He recalled having used this method in Chemistry and applied it to the problem of finding the amount of water in soil. Then it was Martin who dealt with the idea of how and when to take measurements. During this activity, group A worked very well together, in fact when I approached them the first thing that Martin said was “Miss today it is true group work, much better than usual.” This also implies that he felt that normally they do not work as a group and today was something special. This statement also implies that although most students know and appreciate what characterises a collaborative group, yet they still tend to choose not to collaborate with each other.

Group A started off not working collaboratively and just following what one group member claimed to be the best method to solve the problem. As the investigations progressed there was a marked improvement in the way the students communicated and helped each other to solve the problem. By the final investigation, they were working together towards a common goal; therefore one can conclude that they learnt how to work collaboratively.

5.2.2. Student group B

This group was composed of four students of the highest achievement level within the class and they chose to work together. The first thing the group did was choose one person to read the situation out to the rest of the group and then they spent a few minutes thinking individually how they would go about solving the problem. Each student then voiced his opinion about how they should go about solving the problem at hand.

After discussing their plan and the reasoning behind it, they chose the best method as a group and filled in the planning sheet together, going over any difficulties to ensure that everyone understood what will be taking place and then started the experiment. Overall I was impressed with the ease with which they were able to work as a group and how easily they solved the problem. There were never any noticeable conflicts.
between the group members and they were never rude or disrespectful towards each other. They each had their opinion which they wished to voice and they all listened to each other and they reached a compromise, no-one in the group was ignored or excluded.

On the second day of investigations, Lee was absent as he was sick. At first there was some tension between Dale and Michael as Dale tends to pick on Michael especially since Lee was not present. Yet after I intervened to stop their dispute, they started working on the investigation. Most of the discussion took place between Sven and Michael as Dale was silent and did not suggest a possible method; he was just being passive and agreeing with his group. Contrary to what had happened on the first day of investigations, the group did not succeed in working well together. This could have been because of the dispute between Dale and Michael which took place at the beginning of the lesson. This conflict between group members resulted in the group compromising the mutual respect which was important for effective collaborative work.

On the last day of investigations Lee was back at school and the balance in the group seemed to have been restored. Since Lee was Michael’s closest friend, Michael felt much more at ease with Dale and Sven. With Lee back in the group, they proceeded in the same manner as they had in the first investigation as each member contributed equally to solving the problem. The following is the discussion which took place between the students while they were discussing the best possible method:

Lee: “Since water evaporates, the best way of measuring water content would be by evaporating the water and seeing how the mass changes”.

Michael: “How can we heat the soil?”

Dale: “We can either use the Bunsen burner or some kind of oven.”

Sven: “I think we should use the evaporating dish or crucible… like we do in Chemistry when we separate salts from water.”

Mercer (2002), describes the type of discussions which took place within this group on the first and last day of the investigations as being ‘exploratory’ defined as: “exploratory talk is that in which partners engage critically but constructively with each
other's ideas" (p.150). This group worked well together consistently throughout these activities.

Overall this group succeeded in treating all its members equally and working in a collaborative manner most of the time. The only time when there was conflict was when Lee was not present. This contradicted what Oakley, Felder, Brent, & Elhajj (2004) claimed would happen if a group is composed of academically strong students only, they said that these students would “often adopt a divide and conquer policy, parcelling out and completing different parts of the assignment individually and putting the products together without discussion” (p.11). The students in this group did not ‘divide and conquer’, they respected each other’s opinions or suggestions and they took the time to help each other when one person did not understand.

5.2.3. Student group C

In the first investigation, this group did not work collaboratively as Dean came up with a method and he did not give the other group members a chance to challenge his ideas or to think of another way of solving the problem. Ben understood Dean’s plan but Steven did not, the following is the conversation between the group members:

Ben “We need to make the soil particles separate according to their size.”

Steven: “I am not understanding… what do you mean?”

Dean: “I think if we use different sieves of differently sized pores we can separate them according to their diameter.”

Ben: “Yes that should work”

Steven: “Can you explain again? I am feeling lost.”

Dean: “Don’t worry, when you see us do it you will understand.”
Dean and Ben took over and did not even bother to explain to Steven, they just expected him to catch up with them as they went along. Although Steven did not understand, he just followed orders and they worked through the task with minimal conflict between the group members. This idea of one member being more prominent than another was discussed in the work of Kotsopoulos (2010), who found that sometimes a student would take on the role of “the foreman” and the other students in the group would take on the role of “the labourer” (p.122). This is a clear example of group work which was not collaborative as they were not working together and helping each other to achieve a common goal.

On the second day of investigations, the group dynamics were very different since Steven was the one who thought of the solution to the problem first. He then tried explaining how to carry it out to his friends. Yet Ben and Dean had another method in mind and they were not giving Steven the time to explain his method. This lead to a form of ‘disputational talk’, defined by Mercer (2002), who claimed that very often:

“when pupils are allowed to work together in groups most of their talk is either disputational or blandly and unreflectively co-operative, only involving some of the children and providing no more than a brief and superficial consideration of the relevant topics” (p.148).

For this reason I chose to intervene and discuss the investigation with the students to help them to make the right decision. After discussing key words in the problem, the group were able to conclude that Steven’s method was the one which would be able to solve the problem. Steven unlike Dean, took the time to help his group to understand his method and how it can be used to solve the problem. Through discussion of the method and suggestions by Ben and Dean on how to improve the method, this group started to become more collaborative.

On the final day of investigations this group sat down together and discussed the problem given to them as a group. They discussed the problem and thought of ways of solving it together, all members of the group had equal say in what was to be done unlike in previous investigations, this is a part of their discussion:

Ben: “Why don’t we use distillation like we had done in chemistry?”

Steven: “Let us ask the lab technician whether this is possible or not.”
Dean went to ask the laboratory technician but the technician did not think this method is a good idea.

Dean: “He told me that this method would introduce too many variables to the experiment”.

Steven: “Okay so we need to come up with another method.”

Ben: “Water evaporates at 100°C, so if we weigh the soil and then heat it and weigh it again we should be able to find the amount of water which was lost from the soil.”

Steven: “Yes this makes sense, how shall we heat the soil?”

Dean: “The best way would be in an oven so that all the soil will be heated equally.”

Ben: “If we put it in the oven it will be difficult to take regular readings of the temperature because of the high temperature.”

Steven: “Or else we can put a sample in a crucible and heat it on a Bunsen burner, as it will be easier to record the temperature?”

Dean: “Yes good idea and we should allow it to cool in a desiccator to achieve more accurate results.”

As can be seen from their conversation, by the final investigation the group members succeeded in treating each other as equal members who listen and build on each other’s suggestions. Although this group was not collaborative throughout the investigations, they did succeed in improving the way they worked together in order to maximise learning.
5.3. Conclusion

All the students in this study claimed that they were most comfortable with the members of their group and would not have felt comfortable within any other group. The reason why they felt this way depended on their ability and their previous experiences. Higher achieving students wished to work with other high achievers since they wanted to be in a group where someone else can help them and they felt comfortable. The lower achieving students in this study did not wish to be in the same group as the high achievers. Their reasons were that had they been with these students, they wouldn’t have been given a chance to think and share with the group because their opinions would not have been heard or given importance.

In the friendship groups formed in this study, low and medium achieving students were given more opportunities to share their opinions and ideas, this left them feeling more confident and motivated. Not all groups started the investigative tasks working collaboratively yet over the period of the study, I observed my students improve in the way they worked and communicated as a group. From my observations collaboration can only take place when each member feels valued, respected and is treated equally by the group. The next chapter will conclude and discuss implications of the outcomes of this research.
Chapter 6

Conclusion
6.0. Introduction

This study sought to investigate whether IBL can be used to teach a Biology topic which is generally considered to be uninteresting by students.

The main research questions of the study were:

- Will fifteen year old Biology students be able to apply learnt inquiry/problem solving skills to a problem solving task, whilst still learning topic content?
- To what extent do fifteen year old Biology students work collaboratively when dealing with inquiry tasks?

The next section will describe my experience while using an IBL pedagogy.

6.1. My experience of using IBL

Inquiry based learning and problem based learning proved to be a means of engaging students with a topic which is often considered to be boring. Through IBL, the students were truly interested and enthusiastic about their ‘Soil and Agriculture’ lessons. I also noticed that students were extremely cooperative and hard-working throughout these lessons. Students who were often distracted and disruptive in traditional lessons were on task throughout the IBL lessons as they always had something to do or a problem which needed solving. Therefore classroom behaviour improved significantly throughout these lessons and I rarely had to correct my students’ behaviour. Apart from always being on task, all students of different abilities felt that they were contributing to the tasks and even students who were low achievers experienced success through IBL.
Throughout this experience my role as a teacher changed drastically as I was no longer the one imparting knowledge to my students, they were now creating their own knowledge through what Martin-Hansen (2002) describe as, “working directly with the concepts and materials, equipment and so forth” (p.25). In a traditional lesson, I was the one who was continuously passing on information to my students. Communication between students was minimal and by the end of the lesson I was never sure whether all of my students understood, as some students were passive throughout. Traditional lessons left me feeling tired, in comparison, the IBL lessons, felt like a breath of fresh air as most of the effort on the teachers’ part took place before the actual lesson in the preparation.

Throughout the IBL activities my role shifted to that of a facilitator who continuously moved around the class to guide and aid students in the tasks. The students on the other hand, were given a more active role in their learning. Camenzuli (2012), had a similar experience with IBL, he said “students took the centre stage and I took a secondary role; that of a facilitator” (p.69). This shift in the role of the educator was described accurately by King (1993) as “from the sage on the stage to guide on the side” (p. 30).

Since I was constantly observing and discussing with my students throughout the tasks, it was easy for me to determine who did not understand and how I could help them to move forward. The role of the educator is described by King (1993) as being “to facilitate students' interaction with the material and with each other in their knowledge-producing endeavour” (p.30). Through these lessons I felt that I really improved my relationship with my students as I was supporting them in their learning and not just telling them what they should know. This situation was also experienced by Grech (2010), who claimed that her IBL lessons gave her “ample time to also get to know the students which enhanced our relationship” (p. 143).

The next section will summarize the main findings of the study by taking each research question in turn.
6.2. Summary of main findings

6.2.1. Were fifteen year old Biology students able to apply learnt inquiry skills to a problem solving task, whilst still learning topic content?

- Most students were successful in applying the inquiry skills which they learnt to problem solving task. In most of the tasks, the students were capable of: writing a prediction, choosing a method to test their prediction, thinking of scientific questions related to the problem, identifying different types of variables and thinking of ways of collecting and presenting results.

- All the collaborative groups, succeeded in solving the problem presented to them. The students of lower achievement benefitted the most from these tasks as they sometimes depended on other members of the group who were academically stronger. Yet these students were not passive since they also contributed to the success of the group.

- In the individual task some students struggled as they had nobody to discuss their work with or because they were insecure and unsure about the method which they proposed. The students who found difficulty were not all low achievers. Therefore problem solving skills are not always linked with high achievement scores in traditional examinations.

- Students found difficulties both collaboratively and individually when writing precautions which were specific to the task given. The reason for this was probably because no inquiry skills lesson dealt explicitly with writing precautions. Students who study Biology are not normally taught specifically how to write precautions, it is a skill which they are expected to pick up throughout the years. When conducting ‘recipe-type experiments’ students tend to depend on their teachers for precautions and normally precautions are already thought of by the teacher who creates the laboratory sheet which
students are given in a laboratory session. This is highly related to what Dewey (1910) said about science teaching; “science teaching has suffered because science has been so frequently presented just as so much ready-made knowledge” (p. 124).

- Although most of the students found difficulty in writing precautions, most successfully identified which variables should be kept constant and which should be changed. By distinguishing between the variables, the students were inadvertently also carrying out a fair test and even though they could not explicitly identify the precautions they were taking, they were still trying their best to carry out an accurate experiment.

- Another part of the research question which was of particular importance was whether the students would still learn topic content when they are taught through an inquiry based approach. The students’ achievement in the end of topic test gave an insight into whether or not they succeeded to do so. Overall most of the students did well in the end of unit test, some students who had failed previous tests succeeded in achieving a good mark in this test. Some low achievers’ performance actually improved. This shows that although they learnt the topic of “Soil and Agriculture” through IBL pedagogy, they still learnt the subject knowledge which allowed them to be successful in ‘exam-style’ questions.

6.2.2. To what extent were fifteen year old Biology students able to work collaboratively when dealing with inquiry tasks

- With regards to solving the inquiry and problem based tasks, a collaborative setting benefitted most students, especially those who were weaker in the subject and who were grouped with their friends.
Friendship groups were beneficial as the students felt both secure and comfortable within their group. Students appreciated the fact that they were respected within their group and that they were able to contribute to their groups' success.

In the beginning of the investigations, not all of the groups were working collaboratively. In fact most groups had disagreements because either one person was taking over or because one person was doing nothing. Students succeeded in working collaboratively only when all group members were doing their share of the work and helping each other. By the fourth investigation all student groups succeeded in working collaboratively.

All the collaborative groups, succeeded in solving the problems presented to them. The students who gained the most from the collaborative tasks were the students of low achievement as they sometimes depended on other members of the group who were stronger than them academically. Although they sometimes depended on stronger members of the group for support, these students were not passive since they also contributed to the success of their group.

6.3. Strengths and limitations of the study

The main limitations of this study were the following:

- The study took place with a relatively small group, made up of ten students.
- The participants of the study were all male and from a Church school.
- The IBL pedagogy was implemented using one topic from the Biology SEC syllabus. The results obtained were specific to the topic of ‘Soil and Agriculture’ and it is difficult to say whether the results would have been the same with another topic.
As a case study, the results obtained are difficult to generalise especially since the number of participants was relatively small. Yet one must also keep in mind that the aim of case studies is described by Cohen, Manion and Morrison (2007) as “not having to seek frequency of occurrences” as one would expect in quantitative research but they “can replace quantity with quality and intensity, separating the significant few from the insignificant many instances of behaviour” (pp. 257-258).

Case studies can only be ‘generalised’ by what Bassey describes as “fuzzy generalization” (p. 7). Fuzzy generalizations, when contrasted to scientific generalisations, do not offer the same kind of unchanging results expected in scientific research. Fuzzy generalizations “should be used for the kind of statement that says: in cases similar to the cases studied it may be found that x leads to y” (p.7).

Therefore in the case of this study, the context was limited to a group of male students in a mixed-ability class between the ages of 15 and 16 who are being taught a Biology topic through inquiry. Through this study I feel that I have given a true picture of the case which was studied, as it was explored through different methodological tools in order to give the real picture of the case which was studied and the participants involved. According to Devetak, Glažar, and Vogrinc (2010), a number of research tools can be used simultaneously to bring about methodological triangulation, which renders qualitative research more valid and reliable.

My research findings may not be generalizable yet they still have a lot to offer to teachers who are interested in IBL and the use of collaborative learning in the Biology or Science classroom and therefore the results are relatable to those interested.
6.4. Possibilities for future research

Further knowledge about the application of IBL and PBL in the Biology classroom could be collected through different case studies which explore different ways of applying these pedagogies to the everyday teaching of the subject. The following research questions may be of interest to other researchers who are interested in the area which was investigated:

- How can IBL be implemented in various topics of the Biology SEC syllabus?
- How can formal assessment practices be adapted to an IBL pedagogy?
- How can collaborative learning be implemented across the curriculum?
- What is deterring teachers from incorporating IBL in their classrooms? How can teachers be supported through curricular programmes or training?
- Do all students benefit from an IBL pedagogy? What difficulties do students experience in an IBL classroom and how can these students be supported in their learning?
- A similar study could be repeated within a girls or co-ed school setting in order to understand whether the students would succeed in collaborating or not.

6.5. Implications for practice and recommendations

My experience through this case study has allowed me to appreciate and advocate the use of IBL within a collaborative setting within the science classroom. Collaborative groups when used successfully really serve to motivate and encourage students to help each other, work together and build better relationships with their peers. Yet for collaborative learning to be more successful and effective, I recommend that it should be introduced in primary schooling and should be used consistently throughout a child’s education.
Through an IBL pedagogy, students of a range of abilities can be challenged and allowed to experience success, a situation which is very different from that in the traditional classroom. The students in my study benefitted from the inquiry skills lessons and I feel that these should be included in the learning programme of students studying science. Apart from the inquiry skills incorporated in this study, I also recommend including the skill of ‘writing experiment specific precautions’ as the students in this study struggled when it came to writing precautions for the experiments being carried out. I recommend that other teachers who are reading this research should try to incorporate similar lessons which focus on inquiry skills in their programme of lessons. These skills lessons really help students especially during experiments and not just in Biology, but also in Chemistry and Physics.

Following my study, I myself have utilised IBL in my lessons whenever possible as my students clearly enjoy these lessons and experience more meaningful learning because of them. The topic of ‘Soil and Agriculture’ was easily applied to everyday life but this is not the case with all of the topics in the Biology SEC syllabus. Yet one must also keep in mind that IBL according to PRIMAS (2011a) takes place whenever “students are guided to pose questions, to gather and analyse data and to construct evidence-based arguments” (p.5). Therefore a teacher can create this situation by showing students newspaper articles on discrepant events or by presenting them with a problem, in this way most topics can include an element of inquiry.

IBL and student centred pedagogies have been highly recommended by the NCF (2012), yet teachers need to receive continuous training and more resources exemplifying how they can implement these pedagogies in their classroom. According to the NRC (2000), “for students to understand inquiry and use it to learn science, their teachers need to be well versed in inquiry and inquiry-based methods” (p.87). Harwell (2003) claims “we cannot expect students to change what they do if we are content for teachers to continue doing what they have always done” (p.3). According to Anderson (2002), teachers need to be themselves firm believers of the benefits which they and their students will reap through IBL before they choose to implement IBL in their classroom. This change in the way teachers view inquiry can only be achieved through continuous professional development which according to Harwell (2003) is not
a onetime event but a process within which teachers need to be supported and monitored.

Barrett (2005) claimed that trying to change a whole school or university to a student centred pedagogy would be difficult since a short staff development programme about the new pedagogy would not be enough to change a philosophy of teaching overnight. Due to the benefits of IBL, I recommend that it is adopted across the curriculum in order to achieve a student-centred education system and not just in science but in all subjects.

Another recommendation would be to change the way science is assessed, in order to incorporate more inquiry. A concern I experienced as a teacher was that currently the way science is assessed, tends to encourage teaching for the exam and hence I suggest that apart from a change in the curriculum there should also be a change in the way science is assessed as this would encourage more teachers to utilise this pedagogy in their teaching.

Yet these are big changes which take a lot of time and need structures like committees or working groups, who can work towards bringing about this change.

### 6.6. Conclusion

The findings of this research have proven the benefits of the teaching of specific inquiry skills, including an IBL pedagogy in the science or Biology classroom and collaborative work. Most students who took part in this study appreciated the benefits of doing science in the way it is done by scientists and enjoyed working within a collaborative group.

Hopefully as a result of this study, more teachers will be encouraged to incorporate an IBL pedagogy in their lessons and more students will be given the opportunity to experience a more student centred classroom environment as recommended by the NCF (2012).
References


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PRIMAS (2010). Primas WP 2 – Analysis of national contexts: International synthesis report comparing national contexts, pointing out differences, commonalities, and interesting resources and initiatives proper to be adapted to an international use. Retrieved on 26th December 2014, from: http://www.primas-project.eu/servlet/supportBinaryFiles?referenceId=3&supportId=1297


Appendices
Appendix 1: Permission to carry out research in church schools
The Head,

07th February, 2013

Ms Valentina Aquilina, currently reading for a M.Ed in Science Education at the University of Malta requests permission to conduct a study with a focus group and a personal interview with Biology students (same group) which will be recorded for transcription, at the above mentioned School.

The Secretariat for Catholic Education finds no objection for Ms Valentina Aquilina to carry out the stated exercise subject to adhering to the policies and directives of the schools concerned.

Rev Dr. Charles Mallia
Delegate for Catholic Education
Appendix 2: Consent forms given to the Head of School, the parents/guardians and students in English and the information sheet given to students
Consent form given to the Head of School

Dear ______________,

I am currently reading for a M.Ed degree in Science Education at the University of Malta. I am conducting a study in which I would like to monitor students’ participation and progress while teaching a Biology topic using Inquiry Based Learning or IBL, the method of teaching which is being suggested in the new National Curriculum Framework and in the MATSEC syllabus. I would like to use IBL to teach a Biology topic towards the end of Form 4. I feel that this method of teaching would be very beneficial, motivating and interesting for my students.

I would like to ask for permission to conduct my study at ______________. The study would entail a set of lessons with my Form 4 Biology option group to teach the topic of “Soil and Agriculture”, through Inquiry based learning. I will also be encouraging students to work collaboratively with each other. Data for my research will be obtained through observation of my students while they are working together, I will then meet with my students during the break to discuss their progress through focus groups and an individual interview.

The interviews and focus groups will not take place during lesson time and will therefore not waste time during lessons. All the related material for this topic will be covered in class, the only difference being the way the topic is taught. The identity of the school and the students will remain anonymous as in no part of the focus groups and individual interviews are they asked to reveal their identity. The data collected will only be used for research purposes. Your help is highly appreciated.

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I ________________ give permission to Valentina Aquilina to conduct her research at ________________.

Signature:                                     Date:

________________________________________  ____________________
Consent form given to parents/guardians

Dear Parents/Guardians,

My name is Valentina Aquilina and I teach your son Biology. I am currently reading for a M.Ed degree in Science Education at the University of Malta. I am conducting a study in which I would like to monitor students’ participation and progress while teaching a Biology topic using Inquiry Based Learning or IBL, the method of teaching which is being suggested in the new National Curriculum Framework and in the MATSEC syllabus. I would like to use IBL to teach a Biology topic towards the end of Form 4. I feel that this method of teaching would be very beneficial, motivating and interesting for my students.

As part of this study, I would really appreciate if your son takes part in an audio recorded group discussion and an audio recorded individual interview which will give me a better understanding of the progress of students using this teaching method. These sessions will be recorded since this will help me to transcribe what was said.

The interviews and focus groups will not take place during lesson time and will therefore not waste lesson time. The identity of the school and the students will remain anonymous as in no part of the focus group and individual interview are they asked to reveal their identity. The data collected will only be used for research purposes. Your help is highly appreciated.

Should you encounter any problem you will find my contact details below:

Email: valaquilina@gmail.com

Thanking you in advance,

Valentina Aquilina (researcher) Dr. Josette Farrugia (University Tutor)

I give permission to my son, ___________________________ to take part in an audio recorded focus groups and an audio recorded individual interview related to the study. All information and audio-recordings will be destroyed after the study ends. The names of the students and school which participate in the study will not be mentioned in any part of the study.

Signature:                                                   Date: ___________________________
**Consent form given to students**

Dear Student,

I am currently reading for a M.Ed. degree in Science Education at the University of Malta. I am conducting a study in which I would like to monitor your participation and progress while teaching a Biology topic using Inquiry Based Learning or IBL, the method of teaching which is being suggested in the new National Curriculum Framework and in the MATSEC syllabus. I would like to use IBL to teach a Biology topic towards the end of Form 4.

As part of this study, I would really appreciate if you will agree to take part in an audio recorded group interview and an audio recorded individual interview which will give me a better understanding of your progress as a student using this teaching method. The interview and focus group will not take place during lesson time and will therefore not ‘waste time’ during lessons. Your name will not be used in the study. The data collected will only be used for research purposes. Your help is highly appreciated.

Should you encounter any problem you will find my contact details below:

Email: valaquilina@gmail.com

Thanking you in advance,

Valentina Aquilina (researcher) Dr. Josette Farrugia (University tutor)

I would like to take part in an audio recorded focus groups and an audio recorded individual interview related to the study. All information and audio-recordings will be destroyed after the study ends. The names of the students and the school which participate in this study will not be mentioned in any part of the study.

Signature: Date:

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Information sheet given to students

Dear Student,

The study which I will be conducting is called “An investigation of the development of inquiry skills in Biology students through collaborative work.” Inquiry based learning is a method of teaching science, the way science is done by scientists. My study will be following the way you and your classmates work within a group through observation. I will then be carrying out group discussions which will help me understand the way you worked on the problems together with your class mates in a group. Finally I will be conducting an individual interview which will help me to obtain a clearer picture of your individual experience and whether you have managed to apply the inquiry skills which were taught to you.

Should you have a problem with participating in the group discussions or the individual interviews please let me know.

Regards,

Valentina Aquilina
Appendix 3: The focus group and individual interview questions
Focus group questions

1. Did you feel you could have answered the question on your own? Why?

2. How prepared did you feel to solve the problem, for example: writing a hypothesis etc.? (if students do not answer in detail, question four will be asked)

3. Did the skills related activities which we did previously (for example: how to write a hypothesis or how to ask scientific questions) help you solve the problem which was presented to you today? Or do you wish you had more time to practice the skills prior to the problem?

4. Do you think you solved the problem which was presented to you? Explain.

5. Do you think you had enough time to solve the problem?

6. How did you organize the work within the group? (if students do not answer in detail, question eight will be asked)

7. Did you work together as a group to achieve the tasks or did you divide the work individually?

8. Was it important for you as a group to ensure that everyone understood what was being carried out or was it enough if only one of you understood? Why?

9. How did you decide how the task should be carried out?

10. Was there anyone in your group who ‘took over’?

11. Why do you think this person took over?

12. Was there anyone in the group who was ‘left out’?

13. Why do you think this person was left out?

14. Did you understand the topic in the question better after investigating it as a group?

15. How did you feel about learning/working in a group as opposed to working on your own? Explain

16. List all the things you have learnt whilst working in a group on this activity.
Individual interview questions

Following the individual task, the students were asked the following questions.

With regards to the inquiry task:

1. Did you feel you could answer the question on your own? Explain.
2. How would you rate the task you just did? Easy / of moderate difficulty/ difficult?
3. Why did you rate the task in this way?
4. Do you feel that the skills practice (for example: writing a hypothesis etc.) which were done before the inquiry tasks helped you to solve the current problem? Explain.
5. When you are given a question (like the one you just did), can you mention the main steps you go through in order to solve the problem at hand?
6. Do you think that this way of learning has helped you to better understand the topic of “Soil”? Explain.

With regard to the collaborative task:

1. How did you feel within the group you chose? Explain.
2. Why did you decide to work with the people in your group?
3. Do you think that every person in the group gave the same input? Explain.
4. Do you think you could have done more? Explain.
5. Do you think you could have done more if you were in a different group? Explain why.
6. What would you prefer, being given a role or task by the teacher or deciding as a group how to share work (or work together)?
Appendix 4: Inquiry skills lesson sheets
Science Skills: Working in groups

Advantages of group work:

Disadvantages of group work:

When working in a group every individual should:

For group work to work properly, it is important that we do not:

This collaborative working stuff works best when everyone is actually working together!

Image taken from: http://www.photoree.com/photos/permalink/2531099-16105263@N00
Science Skills: Building a hypothesis

Hi! My name is Ben and I was hoping you can give me some advice.

Two months ago my neighbour and I decided to start growing tomatoes, so we bought some seeds of the same variety and planted them. The problem is that his tomatoes have grown much bigger than mine. What causes the difference in fruit size? What can I do to get my tomatoes to grow as big as his?

The questions Ben is asking about his tomato plants could then be used to form what is said to be a hypothesis (pl. hypotheses). What is a hypothesis? A hypothesis can be said to be a prediction about the results of a scientific investigation. Yet these predictions are not simple guess work, they are based on a person’s observations and their previous knowledge on a particular subject or their past experience.

In science, a hypothesis should be testable; this means that investigations can be carried out to obtain evidence which will prove whether the hypothesis is true or false. The hypothesis in itself should give an indication of how it can be tested. Therefore a hypothesis should be written in this form: If . . . then . . . statement.
Now read the following examples of hypotheses, which of these predictions are testable? Which hypothesis is worded properly? Give a reason for your answer.

| Example 1 | If I give my plants fertilizer, then they will grow as big as my neighbour’s plants. |
| Example 2 | If I get lucky, then my plants will grow bigger. |
| Example 3 | My plants aren’t growing bigger because I don’t water them enough. |

Hints on how to write a hypothesis…

- Before writing the hypothesis, think of questions related to the topic. Then try to narrow down the questions to one question which can be tested scientifically. After choosing the question, write the hypothesis.
- When writing the hypothesis…
  i. Make sure that it is a prediction
  ii. Make sure it can be tested scientifically through an investigation
  iii. Check your wording, a properly worded hypothesis should take the form of an *If… then…. statement.*

Task:

Write a hypothesis for the following question:

“Will different plants respond to light in the same way?”

Worksheet adapted from Pearson Education (2004).
**Scientific Questions**

i. What do you think is the difference between asking a scientific question and other questions?

ii. Give an example of a scientific question.

iii. Look at the following questions and decide whether they are scientific or not:
   a) “What makes this chemical green?”
   b) “What do my friends think of this colour?”
   c) “Why is the woodlouse behaving in this way?”
   d) “Why is green the best colour?”
   e) “Which is more fizzy, Pepsi or Coke?”
   f) “Why do skis slide on snow?”
   g) “Why do offices have white walls?”

iv. Do all scientific questions have an answer? Why?

v. Do you think that the following questions have an answer? Explain your reasoning.
   a) All cells contain a genetic code. Scientists are steadily working out the codes for all living things. So, what is the genetic code of a giraffe?

   b) Is there liquid water under the surface of Callisto (one of Jupiter’s moons)?

vi. Suggest two features of all scientific questions.

Picture taken from: [http://www.toonpool.com/cartoons/little%20scientist_40087](http://www.toonpool.com/cartoons/little%20scientist_40087)

Worksheet adapted from: Levesley (2012).
**Variables and fair tests**

**Did you know...**

When conducting an experiment, a variable is something which can be changed, it can also be called a factor.

In an investigation we can select the values of a variable and then measure the effect on the other variable. The variable which is controlled and can be changed is called the **independent variable**. The variable that is measured is the **dependent variable**. Therefore we can say that the dependent variable depends on the independent variable.

A **fixed variable** is another factor which can have an effect on the dependent variable. These variables need to be controlled throughout the experiment.

For a test to be a **fair test** the only thing which changes the dependent variable is the independent variable. For the reason you need to:

- Identify the independent variable
- Identify the dependent variable
- Stop the control variables changing

**Task one:**

Observe the diagram below which illustrates the set up required to investigate the effect of light on photosynthesis.

1. Which factor is the **independent variable**?

2. Which factor is the **dependent variable**?

3. Which factors need to be kept constant to ensure fair testing?

---

Task two:

Read the following scientific question and then answer the questions that follow.

Does the amount of light affect the amount of mosquitoes found in an area?

1. For the investigation, select the independent, dependent and fixed variables.

_____________________________________________________________________
_____________________________________________________________________
_____________________________________________________________________
_____________________________________________________________________

2. Choose one of the fixed variables and explain why it should be kept constant, what problems would it cause if it is not kept constant.

_____________________________________________________________________
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Worksheet adapted from: Levesley (2012).
How to deal with results

The enzyme pectinase breaks down the substance pectin which binds plant cell walls together. Pectinase is used in the food industry to release juice from fruits in the preparation of commercial fruit juices.

An investigation took place in class where the effect of different concentrations of the enzyme pectinase on the volume of juice extracted from crushed apples. The following results were observed.

<table>
<thead>
<tr>
<th>Time of collection of juice/hours</th>
<th>Volume of juice collected at: 40% pectinase concentration/cm³</th>
<th>Volume of juice collected at: 100% pectinase concentration/cm³</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5.8</td>
<td>7.1</td>
</tr>
<tr>
<td>2</td>
<td>7.6</td>
<td>10.1</td>
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<tr>
<td>3</td>
<td>9.8</td>
<td>12.4</td>
</tr>
<tr>
<td>4</td>
<td>10.4</td>
<td>13.6</td>
</tr>
<tr>
<td>5</td>
<td>11.3</td>
<td>14.0</td>
</tr>
</tbody>
</table>

(Adapted from MATSEC Biology paper 2A)

a. Present the above data in the best way possible. Why have you chosen to do so?

___________________________________________________________________________

b. Is there any other way that the results could have been displayed?

___________________________________________________________________________

___________________________________________________________________________

c. How would you interpret the results obtained?

___________________________________________________________________________

___________________________________________________________________________

___________________________________________________________________________
d. Name factors which should have been kept constant during this experiment. Why

__________________________________________________________________________

__________________________________________________________________________

__________________________________________________________________________

e. What conclusions can be made from this experiment?

__________________________________________________________________________

__________________________________________________________________________

Picture taken from:

http://www.bschool.careers360.com/sites/default/files/MAT-result.jpg
Appendix 5: Inquiry based laboratory investigations
Use your inquiry skills to solve the following problem...

Mark and Jessica were walking through the agricultural part of Buskett when they saw a farmer digging in the soil. Read their conversation below:

Mark: “Jessica look at the soil, I think it is all made up of particles which are all identical in size and diameter”

Jessica: “As far as I know soil is formed through the decomposition of different rocks so I doubt that it is made of identical particles.”

Can you think of a way to solve this problem through an investigation in the laboratory?

You can use the following laboratory apparatus and materials:

Measuring cylinder, beaker, spoon, sieve, water

Don’t forget to think about:

- Formulating your hypothesis
- Asking questions related to the problem
- Fair testing
- How to measure results and how to present them
- The conclusion you reach, based on your results.
| **In this investigation I will investigate** |  |
| **This is what I think will happen** |  |
| **The reasons for thinking this is** |  |
| **What I am going to do is** |  |
| **What I will measure (or look for ) is** |  |
| **The apparatus I need is** |  |
| **The things I will vary/change are** |  |
| **I will record my results by** |  |
| **I will display my results by** |  |
| **I will make the investigation safe by** |  |
Dear Biology Student,

Please help me...I am interested in buying soil to add to my field. I would like to choose a soil which retains water but **does not become waterlogged** when it rains heavily. At the same time I would **not** like a soil which drains easily and dries up quickly. Can you think of a way to solve this problem?

I left you three soil samples to test...please choose the best one.

You are provided with three soil samples, try and determine which sample would be the best choice for the farmer by conducting experiments in the laboratory. Don’t forget, you need to compare the different soils.

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<td>What I will measure (or look for ) is</td>
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<td>The apparatus I need is</td>
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<td>The things I will vary/change are</td>
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<td>I will record my results by</td>
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<td>I will make the investigation safe by</td>
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</table>
I just realized that perhaps it would also come in handy to know which soil actually contains the most water. Try and think of a method to check how much water a soil contains.

You can use the following laboratory apparatus and materials:

Evaporating dish, Bunsen burner, tripod, electronic balance, stop-watch and spoon.

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<td>What I will measure (or look for) is</td>
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<td>The apparatus I need is</td>
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<td>The things I will vary/change are</td>
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<td>I will record my results by</td>
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<td>I will display my results by</td>
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<tr>
<td>I will make the investigation safe by</td>
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</table>
Dear Biology student,

I heard that it is very important to have air in the soil... since I heard it contains oxygen needed by many soil organisms.

So I need your advice before I purchase some soil. I managed to get three samples of soil and I would like you to help me choose the one which contains the most air. Can you help me make the right choice?

You are provided with three soil samples, try and determine which sample would be the best choice for the farmer by conducting experiments in the laboratory. Don't forget, you need to compare the different soils.

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<td>What I am going to do is</td>
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<td>The apparatus I need is</td>
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<td>The things I will vary/change are</td>
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<td>I will record my results by</td>
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<td>I will display my results by</td>
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<tr>
<td>I will make the investigation safe by</td>
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</tbody>
</table>
Appendix 6: The individual tasks
Individual Task: Task A

A farmer asks you to give him advice… he has a plot of land but the soil found on the land is clay soil; he would like you to help him improve his soil to ensure a good level of production.

Suggest an investigation which can be carried out in the laboratory to check whether your suggestions would work.
Individual Task: Task B

A farmer asks you to give him advice… he has a plot of land on the side of a hill; he would like you to help him design his field to ensure a good level of production.

- What problems is this farmer experiencing?
- What would your suggestions be to increase production?

- Suggest an investigation which can be carried out in the lab to check whether your suggestions would work.
Both tasks had this planning sheet attached to them.

<table>
<thead>
<tr>
<th>In this investigation I will investigate</th>
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<tbody>
<tr>
<td>This is what I think will happen</td>
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<td>The reasons for thinking this is</td>
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<td>What I am going to do is</td>
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<td>What I will measure (or look for) is</td>
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<tr>
<td>The apparatus I need is</td>
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<td>The things I will vary/change are</td>
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<td>I will record my results by</td>
<td></td>
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<tr>
<td>I will display my results by</td>
<td></td>
</tr>
<tr>
<td>I will make the investigation safe by</td>
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</table>
Appendix 7: Topic of ‘Soil and Agriculture’ learning objectives and topic overview
Soil Topic Objectives

The topic of soil should be covered over not more than a three week period.

By the end of this topic the following content related learning objectives should be reached.

- Describe the origin of soil.
- List the components found in soil.
- List the main types of soil.
- Discuss the properties of the different types of soils (Size of particles. Do they retain water or do they drain easily? Do they contain a lot of air?)
- Investigate and describe an experiment to investigate water content in soil.
- Investigate and describe an experiment to investigate the air content in soil.
- Investigate the water retention or drainage of various soils.
- List and discuss the various biotic and abiotic soil components.
- Describe soil as an ecosystem in itself.
- Describe various organisms which live in soil.
- Describe the beneficial/harmful effect of soil organisms on the soil.
- Apply what has been learnt about soil properties to issues experienced in agriculture. (For example how to decrease soil erosion, how to change the pH of soil and how to decrease the depletion of nutrients in the soil.)
- Explain the advantages of using natural fertilizer and natural pesticides or biological control instead of chemicals which can remain in the ecosystem.

“Soil and Agriculture” can be split into the following sub-topics:

**Introduction:**

What makes up soil?

What are the biotic and abiotic components of soil.

Where does soil come from?
**Subtopic 1:**

- Inquiry based laboratory task: To investigate the particles which make up soil.

- Inquiry based laboratory task: To investigate the water retention or drainage properties of various soils.

- Inquiry based laboratory task: To investigate the water content of soil.

- Inquiry based laboratory task: To investigate the water content of soil.

Following these inquiry based tasks students should be able to conclude the following:

- Possible particles which make up soil and their properties.

- How the size of a soil particle affects its properties, for example: water retention and air content.

- Which soil type is the most fertile, and what are the properties of a fertile soil.

**Subtopic 2:**

- What makes up soil? (biotic and abiotic soil components)

- Soil as an ecosystem in itself, exploration which could take place in a field.

- How do various organisms which live in soil affect it? Describe their beneficial/harmful effect on the soil.

**Subtopic 3:**

- How to improve the properties of a particular soil.

- Apply what has been learnt about soil properties to issues experienced in agriculture. (For example how to decrease soil erosion, how to change the pH of soil and how to decrease the depletion of nutrients in the soil.)

- Using natural fertilizer and natural pesticides or biological control instead of chemicals which can remain in the soil.

- Contour ploughing, strip cropping, crop rotation and terracing in order to decrease soil erosion and nutrient depletion.
Appendix 8: End of topic test
Test on the topic of soil

1. Name and describe the process by which soil is formed.
   ____________________________________________________________
   ____________________________________________________________
   ____________________________________________________________ (3)

These are the components of a soil sample:

<table>
<thead>
<tr>
<th>Clay particles</th>
<th>Humus</th>
<th>Stones</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
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</tbody>
</table>

The soil sample is stirred up in a jar with water and allowed to settle.

a. In which order are the soil components found in the jar (starting at the top)?
   ____________________________________________________________ (2)

b. A second soil sample also has silt in it. It is mixed with water and allowed to settle.
   Between which layers is the silt found?
   ____________________________________________________________ (1)

c. What kind of soil is made from 40% sand, 40% silt and 20% clay?
   ____________________________________________________________ (1)

d. What is humus made from?
   ____________________________________________________________ (1)

e. Some farmers add humus to soil. Give TWO benefits of adding humus to soil
   ____________________________________________________________
   ____________________________________________________________
   ____________________________________________________________
   ____________________________________________________________ (2)

f. A biology student took different soil samples from Buskett. These samples were tested and results showed that soil taken from an area full of the leguminous plant clover had a high content of nitrates. Explain.
   ____________________________________________________________
   ____________________________________________________________ (2)

Total ___/12 marks
2. Chris would like to understand the drainage properties of different soils. Draw a **labelled diagram** of the apparatus he needs to test soils for their drainage properties in the space below.

b. Mention three things he should do in order to make the test fair.

___________________________________________________________________________
___________________________________________________________________________
_________________________________________________________ (3)

c. The table shows the results Chris obtained after testing three types of soil. Fill in the last column of the table with the name of the type of soil which he studied.

(3)

<table>
<thead>
<tr>
<th>Soil Sample</th>
<th>Volume of water poured in cm³</th>
<th>Volume of water collected in cm³</th>
<th>Soil Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>100</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>100</td>
<td>95</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>100</td>
<td>80</td>
<td></td>
</tr>
</tbody>
</table>

Total ___/9 marks
3. A MEPA report about local soil stated:

Around 77% of soils in Malta are either loamy, clay loam or clay soils and have clay content higher than 48%. Such soils may be difficult to work but have higher nutrient retention and water filtration capacities.

Source: SOER05 Background Report – Soil MEPA

a. In clay soils the spaces which are found between soil particles are small. Explain how this affects soil air.

___________________________________________________________________________

___________________________________________________________________________ (2)

b. Why is air in soil very important?

___________________________________________________________________________

___________________________________________________________________________ (1)

c. What can a farmer do in order to improve this air content of his soil?

___________________________________________________________________________

___________________________________________________________________________ (2)

d. Explain why soils with a high clay content may be difficult to work.

___________________________________________________________________________

___________________________________________________________________________ (2)

e. Name the type of soil that is loose, light and easy to dig.

___________________________________________________________________________ (1)

f. Name and describe the mode of nutrition which releases minerals into the soil.

___________________________________________________________________________

___________________________________________________________________________ (2)
g. The MEPA report states that one of the main threats to soil is soil erosion.

(i) Describe TWO ways how soil erosion may occur.

___________________________________________________________________________
___________________________________________________________________________(2)

(ii) Describe TWO farming practices that decrease the chances of soil erosion.

___________________________________________________________________________
___________________________________________________________________________(2)

h. Earthworms present in soil collect leaf litter from the surface and take it to their burrows. Explain why this is beneficial to the soil.

___________________________________________________________________________(1)

i. Describe another way in which earth worms are beneficial to the soil.

___________________________________________________________________________(1)

j. There are various agricultural practices which help farmers when their fields are found on the sides of hills. Among these practices are: building rubble walls, strip cropping, contour ploughing and terracing. Choose any two of these practices and explain how they help farmers over-come the problems which they encounter in this situation.

___________________________________________________________________________
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___________________________________________________________________________(4)

Total_____/ 20 marks
Appendix 9: The inquiry task given six months after the inquiry skills lessons
Problem to solve...

Jellies are made from gelatine. Gelatine is a protein made from animal products. When it is dissolved in hot water and allowed to cool, gelatine forms a three dimensional network of molecules that holds water rather like a sponge.

![Diagram of gelatine molecules forming a network](http://www.thenakedscientists.com/HTML/content/kitchenscience/exp/science-of-fruit-jellies/)

Party jellies are just gelatine with added sugar, fruit flavouring and colouring. Many people like to add fruit to jellies but you will not be able to make jellies with certain fresh fruit such as pineapple, kiwi fruit or papaya – the jelly will not set. However, tinned fruit can be added and the jelly will set without difficulty. N.B. in the tinning process, the fruit is first placed in a hot sugar solution and then it is tinned or placed in a jar with the sugar solution. After the fruit and sugar solution are packed, the jars/cans are then placed in a high temperature water bath for 15 minutes. The jar/cans are allowed to cool and they are ready for storage or consumption.

Task one:

a. Think of **scientific questions** related to the situation above and write them below:

___________________________________________________________________________
___________________________________________________________________________
___________________________________________________________________________
___________________________________________________________________________
b. What factors make a question scientific?

__________________________________________________________________________

__________________________________________________________________________

Task two:
Think of a testable hypothesis for the situation above.

__________________________________________________________________________

Task three:

a. Think of a method you could use in order to test your hypothesis.

__________________________________________________________________________

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b. Which variables would you change and which should be kept constant (fixed variables)? Give a reason for your choice and how it would be a fair test.

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(c. In the investigation which factors are the independent variables and which are the dependent variables?

__________________________________________________________________________
Task four:

a. How would you deal with the results from this investigation?

__________________________________________________________________________
__________________________________________________________________________
__________________________________________________________________________

b. How would you display the results obtained?

__________________________________________________________________________
__________________________________________________________________________