Change in science teacher practice towards IBSE

Author

Catherine Corbett B.Sc., M.Sc., Ph.D.

Thesis submitted to Dublin City University for the degree of

Master of Science

School of Physical Sciences

Centre for the Advancement of Science Teaching and Learning

Dublin City University

2014

Research supervisors

Dr Paul van Kampen

Dr James Lovatt

Declaration

I hereby certify that this material, which I now submit for assessment on the programme of study leading to the award of Master of Science is entirely my own work, that I have exercised reasonable care to ensure that the work is original, and does not to the best of my knowledge breach any law of copyright, and has not been taken from the work of others save and to the extent that such work has been cited and acknowledged within the text of my work.

Signed_________________________________

(Candidate) ID No_____10118519__________

Date: _________________

Contents

Abstract

Change in science teacher practice towards IBSE

Catherine Corbett

Dublin City University

This study reports on the introduction of inquiry-based science education (IBSE) to the classroom through teacher professional development. The study occurs in three phases. Teachers initially participated in a professional learning community (PLC) in Phase 1 of the study. They then participated in a community of practice (CoP) in Phase 2.

In Phase 1 teachers (as a PLC) were introduced to the concept of teaching by inquiry and delivered Topic 1 to students in the junior cycle of secondary school. Teachers and students encountered challenges. This did not deter most of the teachers who continued to the next phase. The teachers in Phase 2 became part of a CoP that developed resources for two more inquiry based topics to be taught by them in the classroom.

Professional development of science teachers using CoP appeared to be effective as a vehicle for teachers to grow in understanding of IBSE in this study. Teachers continued to implement inquiry learning in other classes outside of the study with different resources and so introduced inquiry at a school department level. CoP may be used as a model for teacher professional development to introduce IBL into the classroom.

Acknowledgements

Thank you Jim, Bill and Stephen for your support, encouragement and cups of tea. Thanks Carol for your help.

Thank you Paul and James for lively and stimulating conversations.

Thank you to Aidan, Bije, Emer, Marie and Siobhan whose enthusiasm. inside and outside the classroom made this happen.

And of course, what would I do without Terry and Niamh? They are the best listeners in the world.

List of Tables

List of Figures

Abbreviations and Notes

CASTeL	Centre for the Advancement of Mathematics and Science Teaching and Learning
CoP	Community of practice
DCU	Dublin City University
DES	Department of Education and Science
DJEI	Department of Jobs, Enterprise and Innovation
IBL	Inquiry based learning
IBSE	Inquiry based science education
NCCA	National Council for Curriculum Assessment
NRC	National Research Council
OECD	Organisation for Economic Co-operation and Development
PD	Professional development
PDST	Professional Development Service of Teachers
PISA	Programme for International Student Assessment
PLC	Professional learning community
PSTE	Personal science teaching efficacy
SDPI	School Development Planning Initiative
STEBI	Science teacher efficacy beliefs instrument
STOE	Science teacher outcome expectancy
TALIS	Teaching and Learning International Survey
TIMSS	Trends in International Mathematics and Science Study
T1-6	Teachers 1-6

All Teachers are referred to as “she” or “her” to maintain anonymity.

Chapter 1. Introduction and Background

In this study I set out to increase the use of inquiry based science education (IBSE) among the science teachers in my school through provision of professional development workshops and development of CoP. In this chapter I will outline what inquiry means to me, how this study evolved, the current school curriculum, why IBSE is relevant to the current secondary school curriculum, and my primary and secondary research questions.

Inquiry is a heterogeneous term and is known by other names such as guided learning, guided inquiry or inquiry based learning all of which are inductive methods of teaching. Inquiry based learning means to me that students can actively learn with an emphasis on questioning, analysing data, thinking critically and applying concepts. This is achieved using varying degrees of scaffolding starting with confirmation inquiry, structured inquiry, guided inquiry and finally open inquiry as outlined by Banchi and Bell (2008).

About four years ago I was given the opportunity to attend a Summer School at Dublin City University called “Junior Certificate Science by Guided Inquiry”. This was a three week long course learning physics by inquiry run according to the methods of Lillian McDermott’s group (Seattle, Washington, USA). This Summer school gave me a number of insights. Firstly, teachers need to learn in the same way that they would teach the student. Secondly, incorporating new information around the existing knowledge provides a better platform for retention of new information and thirdly, learning by inquiry improves retention of subject matter as it is better understood as the student has to think critically to understand science.

1.1 The Current School Curriculum

This basis for using IBSE exists in many forms within the current school system. Second level science students follow a science syllabus where they are required to undertake at least 30 experiments and complete 2 major investigations and undertake a terminal assessment for their Junior Certificate. While the syllabus encourages the use of IBSE, teachers do not need to teach by inquiry for their students to achieve good grades in the terminal examination (after 3 years of science) (Department of Education and Science (DES) 2003. Some of the stated aims and objectives of the Junior Science syllabus (DES 2003) are outlined below:

Aims:

Encourage the development of manipulative, procedural, cognitive, affective and communication skills through practical activities that foster investigation, imagination, and creativity
Provide opportunities for observing and evaluating phenomena and processes and for drawing valid deductions and conclusions
Enable students to acquire a body of scientific knowledge appropriate to their age and an understanding of the relevance and applications of science in their personal and social lives

Knowledge and understanding objectives:

Important principles, theories and facts relating to science and their applications in everyday living
The scientific method and the concept of a valid experiment
The underlying scientific principles applied to industry at local, national and international level

Skills:

Procedural plans and the of the scientific method in problem solving
Observation, measurement and the accurate use recording of data
Obtaining and using information from a variety of sources
Logical thinking, inductive and deductive reasoning, and the formation of opinions and judgments based on evidence and experiment
The preparation and presentation of reports on scientific topics, experiments, etc.
Independent study and co-operative learning
The application of scientific knowledge to everyday life experiences

If the spirit of the syllabus were followed then all teachers would be teaching using IBSE already. In reality, students *do* complete all experiments and investigations but in practice the level of inductive teaching is really quite low (Gleeson 2012).

In the experience of the researcher that science teachers fear that they will not have time to complete a large syllabus over the three year period leading up to the terminal examination (the Junior Certificate) if they teach by inquiry. This is consistent with the findings of Tobin and McRobbie (1997). The syllabus includes physics, chemistry and biology topics. The terminal examination accounts for sixty five percent of the final mark. Ten percent of the marks are allocated to Coursework A that consists of thirty mandatory experiments, and twenty five percent of the marks are allocated to Coursework B where the students perform two investigations in their third year. In the preamble to the syllabus it is recommended that the course requires 240 to 270 hours of contact time. The maximum time that a teacher would have is 268 hours calculated as follows: 33.4 weeks in a school year, four periods of 40 minutes per week for three years. The 268 hours does not allow for Public holidays and official house examinations (3 weeks year 1 and 2 and 2 weeks year 3). If 8 weeks of classes are removed over the 3 years, then the maximum time available to teachers is 247 hours. Teachers find it challenging to finish the course and have time for revision. Introducing inquiry, a pedagogy that is not rewarded in the terminal examination is perceived as time wasting. Teaching and Learning International Survey (TALIS) found that Irish teachers ‘hold somewhat weaker constructivist beliefs, and somewhat stronger transmission beliefs, than teachers in comparison countries’ (Gilleece, Sheil and Perkins 2009, p 6).

Teaching science, using IBSE offers a framework that allows the teacher to incorporate experimentation and a sense of wonder into their students’ learning, as advocated in the Junior Certificate syllabus. However, teachers find many obstacles to doing so such as time constraints, exam focuses on recall, self efficacy, misunderstanding what inquiry is and what is expected of them when they teach by inquiry. The most recent National Council for Curriculum Assessment (NCCA) document (2013, p 2) supports inquiry based learning making it relevant to current secondary curriculum. The document introduction says: "The ability to think critically and creatively, innovate and adapt to change, to work independently and in a team, and to be a reflective learner are prerequisites for life and or the workplace in the 21st century". From the outset, IBSE is placed centre stage in the document indicating a real commitment to inquiry based learning at the NCCA.

1.2 Primary and Secondary Research Questions

Can I change science teacher practice towards IBSE in my school?

This research question was sub-divided as follows:

1. What form of professional development is appropriate to encourage teachers to understand IBSE?
2. What form of professional development is appropriate to encourage teachers to use IBSE in the classroom?
3. How do implementation experiences influence teachers' inclination to use IBSE?

1.3 Summary

I have set out to increase the use of IBSE among the science teachers in my school through professional development. To me, inquiry based learning means that students can actively learn with an emphasis on questioning, analysing data, thinking critically and applying concepts. This may be achieved using varying degrees of scaffolding starting with confirmation inquiry, structured inquiry, guided inquiry and finally open inquiry.

My interest in IBSE began when I attended a Summer School at Dublin City University called "Junior Certificate Science by Guided Inquiry". This gave me my first insight of IBSE. This basis for using IBSE exists in many forms within the current school system. If the spirit of the Junior Science syllabus were followed then all teachers would already teach teaching with IBSE. The syllabus is extensive and so teachers find it challenging to complete the course and have time for revision. The most recent NCCA document (2013) supports inquiry based learning making it relevant to current secondary curriculum. This purpose of this study is to explore how best to change science teacher practice towards IBSE in my school.

Chapter 2 outlines the background literature in this field. Chapter 3 outlines: 1) study overview, 2) research strategy, 3) research tools (preparation and presentation of data, handling and treatment with respect to reliability and validity), 5) ethical considerations, 6) study limitations and 7) topic development and implementation. The results of the study are outlined in Chapter 4. Study conclusions are outlined in Chapter 5.

Chapter 2. Literature Review

2.1 What is Inquiry Based Science Education?

2.1.1 Historical Perspective

William Whewell coined the term "scientist" in 1833. This may not have necessarily been a good idea. Until this time artists and scientists did not see themselves as distinct. The assertion that there was a divergence between the arts and the sciences is usually attributed to C.P. Snow. His "two cultures" Rede lecture in 1959 introduced the phrase into our vocabulary (in Lawless and Pici 1977).

The great examples of artist/scientists include Leonardo da Vinci (visual artist and scientist), Galileo (musician and scientist), Copernicus (visual artist and scientist) and Louis Pasteur who was gifted in drawing and painting. Today the Science Gallery at Trinity College Dublin addresses the interface between science and art. The Science Gallery mission statement is "to ignite creativity and discovery where science and art collide" IBSE encourages creative thinking in science.

Limiting the quest for knowledge and understanding to single disciplines creates a value structure that mirrors the 'inside school versus outside school knowledge' which categories knowledge as *useful* or *not useful.* John Dewey (1916) described "The great waste of school" where a child is unable "to utilise the experience he gets outside of school" and "on the other hand unable to apply in daily life what he is learning in school". It is a case of "why do I have to learn this?" Young (2008) spoke about this separation of 'school and non-school knowledge' and how the latter was not considered to be "educationally worthwhile".

In my opinion, learning about science makes for a history lesson and learning to be a scientist is about inquiry. I believe that if it is science-historians that are required then deductive teaching will deliver that. On the other hand, if we want scientists who will continue to make new discoveries then the implementation of constructivist pedagogies in the classroom is required.

Traditionally teaching was largely didactic. That is, teachers were the font of all knowledge and they relayed this to their pupils. Rote learning and practicing what was learned was the students' role. In reality, pupils' evaluation of learning is that they view the teacher as a provider of explanations that are strongly connected with what pupils know already. This student view of teaching and learning is close to the constructivist pedagogies such as IBL (Wood 2011).

2.1.2 Philosophies of Inquiry Based Science Education

Children learn experientially before formal education starts (Gelman and Brenneman 2004; Gopnik et al. 2004). This continues during primary education, as there are no high stakes examinations. At second level, teachers and high achieving students view factual learning as paramount to success in examinations (Keys and Bryan 2001).

From a European perspective the Rocard report (2007) and long before in the US (National Science Education Council 1996), inquiry learning has been promoted by researchers in third level. There is some resistance among second level teachers to implement inquiry learning in the classroom. This resistance may be due to lower teacher self efficacy according to Taylor and Bilberry (2011). Teachers with strong self-efficacy beliefs seem to be more prepared to experiment with and later also implement new educational practices (Evers, Brouwers and Tomic 2002). Also encouragingly, Lakshmanan et al. (2011) observed a positive correlation between changes in self-efficacy and changes in the use of inquiry based instructional practices.

Dewey was inspired by the challenges of Darwin's theory of evolution; that knowledge is not a definite truth and that if the world is a stream of ever-changing phenomena, knowledge is very quickly made obsolete (Darling and Nordenbo 2008 p 293). It is this view that has created a need now in our quickly developing technological age to change the traditional didactic pedagogies to more fluid inductive pedagogies such as IBSE. In an attempt to address this need to change to more inquiry based pedagogies, the NCCA has included inquiry learning as one of the *Key Skills* in their report Innovation and Identity (2011, p.17).

It is important to look at the philosophy for the use of inquiry based learning, which has critical thinking at its core. A critical thinker is "appropriately moved by reason that can be justified; good reasoning that warrants beliefs, claims made and the actions taken" (Siegel 2003, p.23). Bailin and Siegel (2003, p.188) assert that "critical thinking and so rationality is often regarded as a fundamental aim and overriding ideal of education. To so regard it is to hold that education activities should be so designed and conducted in such a way that the construction and evaluation of reasons (in accordance with the relevant criteria) is paramount throughout the curriculum". In this regard critical thinking and inquiry are basic to education.

Critical thinking is viewed as an analytic process that consists of arriving at the correct evaluations of ideas or arguments. A central task involved in educating for critical thinking is one of fostering in students the ability to assess the probative strengths of reasons. Along with the ability to assess this, critical thinkers must understand the value of good reasoning and being disposed to seek good reasons to assess them and govern beliefs and actions on the basis of such assessment. In addition open mindedness, fair mindedness, independent mindedness, inquiring attitude and respect for others in group inquiry and deliberation are required (Blake et al. 2003, Chapter 10). In this respect, although critical thinking is necessary in all educational disciplines, it is essential in science education if students are to think like scientists as outlined in the *National Science Education Standards* 1996 (Section 2.1.5) "Five Essentials of Inquiry".

Two of the most influential authors in constructivism were Piaget (cognitive) and Vygotsky (social). The constructivist's view of learning holds that people construct their own view of meanings from experience rather than acquired knowledge from other sources. Central to Piaget's theory are the age related learning stages and two key processes: assimilation (interpreting new learning experiences within existing frameworks of knowledge) and accommodation (modifying existing thinking to take account of new learning experiences). In his theory a balance had to be maintained between assimilation and accommodation. Too much assimilation results in no new learning but too much accommodation causes confusion in thinking. This thinking is central to the use of different types of IBSE and the appropriateness of the level of inquiry (Bennett 2007).

Vygotsky emphasised the role of culture and language in the development of thinking processes. This led him to propose that children learn best if placed in an environment which required thinking slightly in advance of their current development level, that is in their 'zone of proximal development' (Scott 2004). This tenet is also appropriate to IBSE.

Cognitive development studies even in infants and children have observed that they are capable of abstract reasoning in science and over time become competent at predicting, observing, testing, measuring, counting, recording, collaborating, and communicating (Gelman and Brenneman 2004; Gopnik et al. 2004). According to Hammond, Karlin and Thimonier (2010, p.1), "Passive teaching style squanders children's intrinsic curiosity, imagination, creativity, and fascination with the natural world and forces universities to invest enormous sums in an effort to recover from these lost opportunities". Haury (1993, p.2) wrote: "There is no authentic investigation or meaningful learning if there is no inquiring mind seeking an answer, solution, explanation, or decision".

2.1.3 Different Forms of Inquiry

Inquiry is a heterogeneous term and is known by other names such as: guided learning, guided inquiry or inquiry-based learning. All of these are inductive methods of teaching. Not only are there different names but also there are different methods of teaching within these names. Prince and Felder (2007) describe inquiry based learning under the following headings: discovery learning, problem based, project based and case based and go on to describe the different levels of autonomy and student resistance to these. Bell, Smetana and Binns (2005) outline a continuum of inquiry: confirmation, structured, guided to open inquiry again outlining the degree of autonomy a student has in the process. Wenning (2010) describes an inquiry spectrum: *discovery learning*, *interactive demonstration*, *inquiry lesson*, *inquiry lab* and finally *hypothetical inquiry*. He later added *real world application* in a revised online version of the paper in 2012.

In the Rocard report (2007 p.10), paraphrasing Linn, Bell and Davis (2004), inquiry based learning is described as "*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*".

Banchi and Bell (2008) divided inquiry learning into four categories based on how much information is provided to the student and how much guidance is given by the teacher.

1) Confirmation Inquiry (Question, Procedure and solution are provided)
2) Structured Inquiry (Question and procedure are provided)
3) Guided Inquiry (Question is provided)
4) Open Inquiry (No guidance is provided)

Structured inquiry was the model used in the current study to teach all three topics. This form of inquiry was chosen as an introduction to both teachers and students who were unfamiliar with teaching and learning by inquiry.

There are many facets to inquiry based learning according to the PRIMAS (2010, p.10) *guide for professional development providers*: "Inquiry based learning (IBL) is a way of teaching and learning mathematics and science in which students are invited to work in the way mathematicians and scientists work. When students are involved in an inquiry learning lesson, they need to put into play their prior knowledge and a wide variety of processes, like simplifying and structuring complex problems, observing systematically, measuring, classifying, creating definitions, quantifying, inferring, predicting, hypothesizing, controlling variables, experimenting, visualizing, discovering relationships and connections, and communicating". The processes students require outlined by the PRIMAS guide are needed to implement inquiry to differing degrees based on the structure of Banchi and Bell (2008).

2.1.4 Confusion over the interpretation of Inquiry learning

Kirschner, Sweller and Clark (2006, p.5) reject the use of inquiry based learning. They equate IBSE with minimally guided learning and state "these approaches ignore…. the structures that constitute human cognitive structure' and 'minimally guided instruction is less effective than instructional approaches". Brickman et al. (2009) acknowledged that the first year university students in the study found that experiencing the complexity and frustrations faced by practicing scientists was challenging and may explain the widespread student resistance to inquiry based learning. The studies of Brickman et al. (2009) and Kirschner, Sweller and Clark (2006) do not address the meaning of inquiry based learning in the classroom nor the value of professional development of those who would teach it. They appear to have missed the point that structured guidance involves as much the training of the teacher in the methodology of delivery of inquiry based learning as allowing for a culture of guided (not open) inquiry which would be of benefit to students. Hmelo-Silver, Duncan and Chinn (2007, p.99) refute their assertions saying that inquiry learning and problem based learning are highly scaffolded "reducing the cognitive load and allowing students to learn in complex domains". Alfieri et al. (2011, p.1) reported that "unassisted discovery learning does not benefit learners, whereas feedback, worked examples, scaffolding and elicited explanations do". In the present study learning is scaffolded on the students existing knowledge. On balance, students benefit from learning by inquiry when well defined inquiry pedagogies (and understanding of how students learn) are implemented. Similarly, Harris and Rooks (2010) explain that inquiry learning must take place in a framework of pre-existing knowledge. McRobbie and Tobin's paper although written sixteen years ago (1997, p.207) has some validity in Ireland today: "A paradox exists is that irrespective of the more than 400 reports that have urged reform at a national level in the United States and scores more have occurred around the world, there does not appear to be an appetite for radical reform among science teachers". Gash and McCloughlin (2010) report resistance among Irish second level teachers citing that teachers felt that constructivist pedagogies were more relevant to primary school students than to second level students

2.1.5 Aspects of inquiry relevant to the current study

It was important to determine what aspects of inquiry I would emphasise to teachers to give them a framework to understand inquiry as part of their professional development. When I initially met the teachers during the professional learning community (PLC) phase, I outlined the four categories outlined by Banchi and Bell (2008). They felt they required more information to teach by inquiry. I used the US National Research Council's *National Science Education Standards* 1996. This outlined "Five Essentials of Inquiry" as follows:

(1) Learners are engaged by scientifically oriented questions.

(2) Give priority to evidence to develop and evaluate explanations.

(3) Formulate explanations from evidence to address scientifically oriented questions.

(4) Evaluate their explanations in light of alternative explanations.

(5) Communicate and justify their proposed explanations.

This description is useful outside the classroom, but would not translate easily or fluidly into the classroom. In my opinion, there is too much detail and not enough context for teachers to internalise and to impart to students. Minner, Levy and Century (2010) performed a synthesis of inquiry based science instruction research and found "the amount of active thinking, and emphasis on drawing conclusions from data, were in some instances significant predictors of increased likelihood of student understanding of science content". The concept of "active thinking" partly describes the "Five Essentials" and is easier for teachers to manage in a classroom environment.

Oliviera (2010) reported that student centred questions prompted larger and more articulated student responses, prompted a higher level of student thinking and positioned students as complimentary experts and encouraged students to conduct authentic investigations. Equally, according to Chin and Osborne (2010), productive discourse helps students verbalize their arguments. This too can guide an inquiry class. Questioning is also at the heart of inquiry learning. Roth (1996, p. 709)) spoke about a “fundamental change in the professional preparation and development of science teachers” and that “questioning is a complex practice which cannot be appropriated easily”. Also on a cautionary note: Abrami et al. (2008, p.1102) commented that “as important as the development of critical thinking skills is considered to be, educators must take steps to make critical thinking objectives explicit in courses”.

2.2 IBSE at policy level

2.2.1 International Policies on Science Teaching

In 1996 the National Research Council in the USA issued national education standards that outlined science teaching and professional development standards. Although many education guidelines have been published since then, no new guidelines describing inquiry learning were published in these documents except to include aspects of inquiry into the teaching of engineering at K-12.

The EU, like the US in the past, does not have pan-EU control of education. All member states write their policies and curricula independently of each other. The authors of the Rocard Report (2007, p.3) were tasked by the European Commission (the executive body of the European Union) to examine initiatives and good practice to find ways to improve young peoples’ interest in science. The Report found, “A reversal of school science-teaching pedagogy from mainly deductive to inquiry-based methods provides the means to increase interest in science” and that “teachers are key players in the renewal of science education. Among other methods, being part of a network allows them to improve the quality of their teaching and supports their motivation” and recommended that “the introduction of inquiry-based approaches in schools, actions for teachers training to IBSE, and the development of teachers’ networks should be actively promoted and supported”.

The EU has funded a number of initiatives to disseminate both teacher professional development and classroom science courses using inquiry based science education. Some of these EU funded projects are: Framework Programme 7, Science and Society projects such as PRIMAS, ESTABLISH, Pathway, Fibonacci, Profiles and S-Team, Comenius projects such as STENCIL and national projects.

In the UK the focus on league tables had resulted in pupils being pressured to attain high grades and so opt for subjects that are seen as easier to get good marks in such as art, drama and history (Gillard 2011). The result was that subjects perceived as more difficult such as mathematics, chemistry and physics were dropped. The National Curriculum is currently under review. In September 2013 a new programme of study in science is to become statutory. In the document outlining the programme of study (Department of Education (UK) 2012) Science Programme of Study for Key Stage 4 the 'pupil should be taught to [work scientifically by]:

1. Experimental skills and investigations
2. Handling information and problem solving
3. Scientific attitudes

The Nuffield Foundation started to produce materials to be taught using inquiry learning in the UK over sixty years ago (Nuffield Foundation 2012). The Foundation set up a project, which sought to modernise science education for all 5 to 18-year-olds. *"I do and I understand"* was the central tenet of the project. In 2008 The Nuffield Foundation produced a report subsequent to a series of seminars and made seven recommendations. Two recommendations from this report are particularly relevant to the current study: "the emphasis in science education before 14 should be on engaging students with science and scientific phenomena. Evidence suggests that this is best achieved through opportunities for extended investigative work and 'hands-on' experimentation and not through a stress on the acquisition of canonical concepts" and that teacher continuous professional development is central to this (Osbourne and Dillon 2008, p.9).

Trends International Mathematics and Science Survey (TIMMS) provides data to benchmark the achievements in mathematics and science of nine to twelve year olds across countries and so provide information to influence policy. Ireland is shown in 22nd position in the TIMSS (2011) science table. Ireland's mean score is significantly lower than 17 countries, including the US, Sweden, Netherlands, England, and Germany. Ireland's mean does not differ significantly from the means for 10 countries (including Italy, Northern Ireland and Australia), and is significantly higher than the mean for 22 countries, including Spain, New Zealand and Norway. Ireland's position on the TIMMS table may be a cause for concern and improvement in the country's scores is important. Finland is among one of the highest ranked countries in terms of student educational attainment. Teacher professional development is considered to be one of the reasons for their success. The aim of the current case study is to explore the effectiveness of teacher PD to improve teachers' understanding, use and inclination to use IBSE in an effort to improve these scores.

PISA (Programme for International Student Assessment) measures the performance of 15 year old students in reading, mathematics and science and collaborates with countries to influence policy to improve student performance. In 2006, Irish science education policy was altered due to the PISA 2006 report where it ranked 17 out of 34 OECD (Organisation for Economic Co-operation and Development) countries. The NCCA focused on science that served to expedite the changes that took place in the curriculum for lower secondary science education in 2003. In other words, PISA has been a driving force for reforms (Figazzolo 2006, p.15).

2.2.2 Policy and Curriculum Development in Ireland

In Ireland in 2003 a revised Junior Science syllabus was introduced in an attempt to improve interest in science and to introduce inquiry learning (DES 2003) in line with the new primary science curriculum (DES 1999). This was in response to the decline in numbers taking science and the consequent expected impact on Ireland's ability to compete for technology driven industry (Taskforce on Physical Science, DES 2002).

The new syllabus has put an emphasis on experimentation and some investigation. This was an attempt to introduce inquiry learning into the curriculum. The introduction of IBL to the Junior Certificate curriculum through experimentation has done little to change teaching methods (Gleeson 2012). According to Matthews (2007) there may be many reasons why teachers resist implementing inquiry learning: it may be in part due to the pressures of course completion, lack of material available to teachers and also a lack of understanding of the four different levels of inquiry. Introducing the new syllabus also did little to improve the uptake of the sciences at second level. In a study of five teachers Henderson and Dancy (2007) outlined seven situational barriers to implementing new pedagogies. These were: students' attitudes towards school, expectations of content coverage, lack of instructor time, departmental norms, student resistance, time structure, class size and room layout.

Gash and McCloughlin (2010) from St Patrick's College Dublin (data from a Comenius Project) look at the Irish view of constructivism in primary and second level education. They make reference to the shift in emphasis to this approach by the NCCA. Primary teachers in Ireland were more positive about the relevance of constructivist teaching methods than their second level counterparts. They also found that "participating teachers were interested in the results often confirming their views on the importance of their own ways of teaching".

2.3 Teaching IBSE

2.3.1 Teachers attitudes to IBSE

Inquiry based learning was introduced in the 1960s in the post Sputnik era by early education reformers. Little attention was paid to professional development and so inquiry based learning was not widely adopted (McDermott 1991).

According to Keys and Bryan (2001) there has been an overt and a covert resistance to the re-introduction of IBSE. Teachers will either say that the course will not get covered on time or that the students will not understand anything afterwards. The students will say that it is a waste of time and that it does not prepare them for the examination (McRobbie and Tobin 1997). The difficulty according to Wilson et al. (2010) is the teachers will sometimes think they are teaching by inquiry and the students will themselves rely on other students to do the work.

Rogoff (1994, p.209) takes the perspective that "learning is a process of transformation of participation itself, arguing that how people develop is a function of their transforming roles and understanding in the activities in which they participate". To understand the activities they participate in they must understand the learning and teaching perspective of the new pedagogy. Abrandt Dahlgren, Castensson and Dahlgren (1998, p.437) focus on inquiry elements of problem based learning and find that it is the way in which inquiry based learning is conceived by the teacher that may explain the difficulties experienced. Unless the teacher revises their teaching method and also the reconsiders the students' learning method, there is likely to be limited success with use of the new method. They explore the difference between *learning* perspective and *teaching* perspective: "Characteristic of the learning perspective is a focus on the students' learning process, while in the teaching perspective focus is on the methodological teaching aspects". They also look at the teacher's role being *supportive* or *directive*: "The students' activity, responsibility and influence on the education were emphasized" when the teacher is supportive whereas "the directive tutor's role was characterised by a restricted view or uncertainty of the teacher's role". They concluded: "Previous experiences have shown that the implementation of [IBL] means more than a change of methods, it requires reflections on the part of the teachers on their conceptions of knowledge and learning".

Studies have shown that inquiry learning makes science more accessible to a greater number of students in terms of race and ability (Wilson et al. 2010; Lynch et al. 2005). In many schools in Ireland, science classes are generally mixed ability and sometimes compulsory to Junior Certificate. The compulsory nature of the subject offers students a chance to experience science more than might otherwise have been the case. In 2002, Gibson and Chase looked at students' attitudes to science in middle school and suggested that those taught by inquiry during summer programmes maintained a more positive attitude to science. They conclude that teachers helping students learn, particularly by encouraging them to ask questions about material covered, was key to the success of the study.

Wilson et al. (2010) conducted a study to investigate the effectiveness of IBL with 14 to 16 year old students. They found that those taught by using IBL reached significantly higher levels of achievement in knowledge, reasoning and argumentation than their counterparts taught by 'commonplace instruction' and continued to do so four weeks later.

Teachers have difficulty understanding what is expected of them when asked to teach by inquiry. Many studies since the 1990's have shown that with teacher preparation, teaching by inquiry can be successfully introduced into the classroom (Lakshmanan et al. 2011, Wilson et al. 2010, Palinscar et al. 1998). Teacher confusion is understandable as there are many descriptions of inquiry learning.

2.3.2 Teacher Professional Development in Inquiry Learning

Different models have been used to promote successful professional development for science teachers to teach by inquiry.

Darling Hammond and McLoughlin (1995) described characteristics of effective professional development as follows:

* Engages teachers in concrete tasks of teaching assessment, observation and reflection

* Engages participants in inquiry refection, experimentation

* Promotes a collaboration between participants and professional developers

* Connects to or is coherent with classroom work.

* Sustains and continues support

* Connects to other aspects of school change.

Loucks-Horsley et al. (1998) look at the failure of short workshop type PD to illicit changes in teacher behaviour and that this form of PD perpetuated traditional pedagogies.

Lotter, Harwood and Bonner (2006) explored the conceptions of inquiry teachers formed during their summer school and looked at the discrepancies between these and the goals of the programme. Their results suggested that teachers engage in identifying key issues in their own PD was an effective strategy. Marshall and Smart (2013, p.140) who also relied on reflective practices: “the sustained experience that appear to support transformation of practice include differentiating to accommodate varied prior knowledge, unique understandings, and different beliefs of the participants. This can be partially achieved by providing group interactions that provide sufficient time for reflective practice to bridge the current PD experience with the individual classroom needs.”

Blanchard, Southerland. and Granger 2009 reported that *research experiences for teachers* (RETs) had merit. They found that the teachers in their study changed to a more student centred approach, engaging their students in conducting their own experiments.

Capps, Crawford and Constas (2012, p.296) reviewed empirical literature on inquiry, professional development (PD) and defined inquiry based science teacher PD as “one that consists of activities that support teachers in creating classroom environments in which students learn science concepts and principles through inquiry, as well as learn about what science is, and how scientists work”.

In the current study I use a PLC model in Phase 1 of the study and a CoP model with reflective practice in Phase 2 in an effort to create a sustained classroom environment in which teachers can learn to teach by inquiry.

2.3.3 Teacher Communities

In the literature teacher professional development is an important part of introducing IBL into the classroom. It was in part this lack of professional development in the 1950s and 1960s that stopped the introduction of inquiry learning (McDermott 1991). Keys and Bryan (2001, p.631) stated that “the efficacy of reform efforts rests largely with teachers, their voices need to be included in the design and implementation of inquiry based curriculum”. To insure the introduction of IBL in the classroom, it was important to introduce it to teachers though a community of teacher learning where they would share ideas and resources to achieve the common goal. In Phase 1 of the study, the teachers participated in a professional learning community (PLC) and in Phase 2 they became members of a community of practice (CoP). I will outline different forms of teacher learning communities and will address PLC and CoP in more detail.

The term "Community of teacher learning" is widely used with many different meanings. Levine (2010) described how different conceptions of teacher community help us understand teacher learning. These were: (1) inquiry community, (2) teacher professional community (3) community of learners and (4) community of practice. He then defined what these categories bring into focus: (1) *Inquiry Community*: "how teachers learn from asking questions and finding answers together", (2) *Teacher Professional Community*: "how shared norms, beliefs and routines affect teachers' work with colleagues and students", (3) *Community of Learners*: "how schools can promote learning for adults as well as students" and lastly, (4) *Community of Practice*: "how people learn from seeing, discussing, and engaging in shared practices".

According to Lee and Shaari (2012, p.1) a PLC "seeds professionalism through emergent best practices" and CoP "consolidates best practices into a coherent professional identity". They go on to state, "with regard to teacher professionalization and professional development, the two share a symbiotic relationship. The distinctive models converge in the ultimate goal of enhancing teacher professional standing". In the present study, the teachers required more guidance initially and so a PLC was more appropriate. As the study progressed, teachers were better placed to become a community that worked together to produce resources that could be implemented using the newly learned pedagogy.

A Professional Learning Community (PLC) is more structured than a CoP where there is active engagement in professional learning aimed at enhancing teacher professional learning identity. The PLC in this study resembled the learning community of teachers who participated in teaching the first topic by inquiry but who did not have any input into its development. Attributes of PLCs as outlined by Hord (1996) are presented in Table 2.1 below.

Table 2.1 Attributes of a Professional Learning Community.

•The collegial and facilitative participation of the principal who shares leadership and thus, power and authority through inviting staff input in decision making • A shared vision that is developed from an unswerving commitment on the part of staff to students' learning and that is consistently articulated and referenced for the staff 's work • Collective learning among staff and application of the learning to solutions that address students' needs • The visitation and review of each teacher's classroom behaviour by peers as a feedback and assistance activity to support individual and community improvement • Physical conditions and human capacities that support such an operation

Vescio, Ross and Adams (2008) reviewed eleven studies of PLC. They found that the collective results suggested that well developed PLCs have a positive impact on both teaching practice and student achievement. This model has the advantage of bringing new knowledge and experience to the community.

Lee and Shaari (2012, p.2) assert, "PLC implementations tend to be predominated by top-down initiatives targeted at shaping teacher identities".

Kwan and Lopez-Real (2010) assert that CoPs are influenced by school culture, personalities of the members and other CoPs. The need to use CoP in the current study became evident as a transformative measure in the study. Lakshmanan et al. (2011, p.14) also reported that teacher collaboration positively impacted teacher efficacy and practice. They go on to report "[their] study provides evidence of benefits gained by sustained professional development over a period of time and the importance of collaborative forms of professional development".

Kwan and Lopez-Real (2010) used a matrix developed by Wenger (2002) to determine the effectiveness of a CoP. He used the term "health" (or effectiveness) of a CoP and described this in terms of *connectedness, expansiveness and effectiveness,* and matched them with three modes of belonging: *engagement, imagination and alignment*. They used this framework to interpret how their subjects' identities formed during the process. In a CoP that has a strong identity connectedness involves shared experiences mutually aiding each other to achieve their common goals. An expansive community is where members of the group also participate in other groups and an effective community is socially enabling for its members. These qualities are then matched against engagement such as doing tasks together and producing resources, imagination, that is how we view ourselves within the social framework and alignment that refers to the coordination of the group so that it can be effective beyond one person's involvement. An example of the sort of question that can be asked using this framework would be: to what extent does a group member's identity affect their interactions and relationships with the other group members during the process or vice versa? Table 2.2 outlines the matrix used by Kwan and Lopez-Real (2010).

Table 2.2 The effectiveness of a CoP (Kwan and Lopez-Real, 2010).

		Qualities of Identity		
		Connectedness (With others as a result of shared experiences.)	Expansiveness (Membership of other communities)	Effectiveness (participation in community)
Modes of Belonging	Engagement (doing things together, talking, producing artifacts)	How does one's engagement within a CoP contribute to the forming of deep connections among members?	How does one's engagement within a CoP contribute to interactions with other CoPs?	How does one's engagement within a CoP contribute to effective action within a CoP?
	Imagination (self image in our surroundings)	How does one's image of self and community help towards forming deep connections with a CoP?	How does one's image of self and community help towards creating interactions with other CoPs?	How does one's image of self and community contribute to effective action within the CoP?
	Alignment (with science department, school and Dept. Education)	How do established alignments contribute to the forming of deep connections within CoP?	How do established alignments help towards creating interactions with other CoPs?	How do established alignments contribute to effective action within a CoP?

McAvinia and Maguire (2011) described four development models for CoP: (1) where an existing network was in place with no visible collaborative development or resource sharing with an existing CoP, (2) where a CoP builds on an existing network and sometimes becomes indistinguishable from the original network, (3) where the CoP stands alone where no previous network existed and (4) where the CoP brings together a number of unlinked networks to focus on a shared collaboration. They also describe four different possibilities for managing CoPs: (1) CoP is almost entirely driven by an outside coordinator who identifies potential developments and events, (2) the coordinator, still outside the CoP, is linked to an internal coordinator who is involved in the administration of the CoP, (3) the coordinator provides a technical resource but is not directly involved in the driving of the CoP activity and (4) the coordinator is an integral member of the community who drives the CoP from the ground up and is a core member of the community.

Levine (2010, p.122) describes the mechanism of learning in a CoP as "legitimate peripheral ongoing opportunities to engage in the practice, moving from peripheral participation to mastery of practice". This means that initially a new member will have the opportunity to participate, as a novice in the community but with time and involvement will also become expert in the CoP's area of interest. The models of Wenger (2002) and McAvinia and Maguire (2011) are incorporated into this study.

2.3.4 Science Teacher Efficacy Beliefs

How teachers engage in using the new pedagogy and how they function in the learning communities can be influenced by their own *science teaching efficacy beliefs* as outlined by Laskhmanan et al. (2011). Measuring a teacher's confidence in their ability to teach is of importance in this study as they are expected to teach using a method that is new to most of them. Bandura and Adams (1977) observed that beliefs are closely linked to behavior and people develop a generalised expectancy about "action outcome contingencies" based upon life experiences. Self efficacy refers to one's own belief in one's own ability to successfully perform a specific task. Riggs and Enochs (1990) validated a Science Teaching Efficacy Beliefs Instrument (STEBI) to measure teacher belief systems as a possible contributor to behavior patterns of in service elementary teachers with regard to science. They formulated two subscales: Personal Science Teaching Efficacy Belief (PSTE) and Science Teaching Outcome Expectancy (STOE). STEBI A (Enochs and Riggs, 1990) is used for in-service teachers and contains 25 questions that are answered using the Likert scale: 1 strongly disagree to 5 strongly agree. Thirteen of the 25 questions relate to PTSE and the remainder assess STOE.

Evers, Browers and Tomic (2002) observed that teachers with strong self efficacy beliefs seemed to be prepared to experiment with and implement new educational practices.

In a study by Azar (2010), teachers' scores on STEBI were not affected by gender or teaching experience but were affected by the subject. According to Ross, (1998), teachers with high self-efficacy show more positive affective behaviour and are more likely to implement new instructional practices.

Van Uden, Ritzen and Pieters (2013) noted that teachers rating themselves higher in self efficacy perceived that students were more engaged. However, they did not indicate whether this translated into better outcomes for the students. Lakshmanan et al. (2011) used this instrument to determine if standards based professional development improved teachers' STEBI scores. They found that there was an improvement in teacher self efficacy but not in outcome expectancy. In the present study the teachers scores were only determined at one point during the study. The results were compared with the average values from Lakshmanan et al. (2010).

2.3.5 Transformation of Teacher-Researcher

As part of the process of introducing teachers in my school to inquiry based learning, I also went through a learning process. Lave and Wenger (1991) refer to learners' identities being 'transformed' through performing new tasks and demonstrating new understanding. Many of the tasks were new to me.

Bell and Gilbert (1996) described a model of teacher development dividing it into three different strands: social, professional and personal development. Each of these was divided into three phases. Social development was divided as follows: seeing isolation as problematic, valuing collaborative work and reconstructing what it means to be a teacher and initiating collaborative ways of working. Professional development was defined under the following headings: trying out new activities, development of ideas and classroom practice and initiating other development activities. Personal development was outlined: accepting an aspect of my teaching as problematic, dealing with restraints and feeling empowered.

According to Marshall and Smart (2013, p.140), "the sustained experiences that appear to support transformation of practice include differentiating to accommodate varied prior knowledge, unique understandings, and different beliefs of the participants". They go on to say that the success of this transformation was partly through group interaction that provided reflective practice to link between professional development and classroom practice.

2.4 Summary

The constructivist's view of learning holds that people construct their own view of meanings from experience rather than acquired knowledge from other sources. This thinking is central to the use of different types of IBSE and the appropriateness of the level of inquiry.

Critical thinking is essential in science education if students are to think like scientists as outlined in the *National Science Education Standards* 1996 (Section 2.1.5) "Five Essentials of Inquiry". Critical thinking is viewed as an analytic process that consists of arriving at the correct evaluations of ideas or arguments.

In the Rocard report (2007), paraphrasing Linn, Davis, and Bell (2004), inquiry based learning is described as "*inquiry is 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*".

In Ireland in 2003 a revised Junior Science syllabus was introduced in an attempt to improve interest in science and to introduce inquiry learning (DES 2003). The new syllabus has put an emphasis on experimentation and some investigation. The introduction of IBL to the Junior Certificate curriculum through experimentation has done little to change teaching methods (Gleeson 2012). Introducing the new syllabus also did little to improve the uptake of the sciences at second level.

Different models have been used to promote successful professional development for science teachers to teach by inquiry. The 5 E's as outlined earlier (NSEC, 1996) have been used for teacher PD. It has been reported that RETs have merit. Others have relied on reflective practices. In this study I use a PLC model in Phase 1 of the study and a community of practice (CoP) model with reflective practice in Phase 2.

How teachers engage in using the new pedagogy and how they function in the learning communities can be influenced by their own *science teaching efficacy beliefs* as outlined by Laskhmanan et al. (2011). Evers, Browers and Tomic (2002) observed that teachers with strong self efficacy beliefs seemed to be prepared to experiment with and implement new educational practices.

As part of the process of introducing teachers in my school to inquiry based learning, I also went through a learning process. Lave and Wenger (1991) refer to learners' identities being 'transformed' through performing new tasks and demonstrating new understanding. According to Marshall and Smart (2013), the success of teacher transformation was partly through group interaction that provided reflective practice to link between professional development and classroom practice.

In the next chapter the methodology used to evaluate this study discussed. In Chapter 4 development of the topics to be taught and the aspects of inquiry associated with them are outlined and how they would implement it in the classroom.

Chapter 3. Methods

3.1 Introduction

In the previous chapter the philosophy of IBSE and its introduction as a teaching method internationally were discussed. The different forms of inquiry and confusion surrounding its definition were discussed. Finally the teacher perspective in terms of how they work together, their belief systems and their professional development were discussed. The purpose of Chapter 2 was to put the research question (Can I change science teacher practice towards IBSE in my school?) in the context of the literature. Most importantly, this study needed to be seen from an Irish perspective. The NCCA through the revised science syllabus (DES 2002) and now through the "Key Skills" initiative (2011) wishes to introduce inquiry-based learning into junior secondary science education.

This chapter is divided into the following sections: 1) study overview, 2) research strategy, 3) research tools (preparation and presentation of data, handling and treatment with respect to reliability and validity), 5) ethical considerations, 6) study limitations and 7) topic development and implementation.

3.2 Study overview

The purpose in of this study as defined in the research question is to introduce IBSE to the science classroom in the target school through teacher professional development. This research uses a case study approach using mixed methodology for data collection. Table 3.1 gives an outline of phases, timeline, data collection, research methods and tools in the study. A detailed account of the research tools used to collect data is given in Table 3.4.

In Phase 1 teachers were introduced to IBL, given resources to implement a topic in the classroom, and asked to return the completed surveys, pre-topic and post-topic tests. The teachers were subsequently interviewed. This was the first attempt to change science teacher practice towards inquiry. The purpose of the student survey, as outlined in the methods was to find through questioning the student if any inquiry learning was already happening in the classroom. Students understanding and retention were assessed in the post-topic tests. The purpose of the pre-topic and post-topic tests is outlined in Chapter 3. The teachers' interviews were studied to find their views of their experiences of teaching by inquiry, what aspects of inquiry they employed, how this differed from their normal class for that topic and what was the students' experience.

In Phase 2 teachers assisted in production of the resources for Topic 2 and 3. Topic and teacher development are outlined in Chapter 3.5. Teachers then implemented the topics in the class. They were asked to return their survey and the students' surveys and any tests that the students had completed. The results of Phase 2 were used to see if teacher practice had changed students' experience of inquiry. Teachers' surveys before Topic 2 and 3 were a mechanism to involve teachers in topic development. The surveys were also used to promote professional development and to gather teacher suggestions to improve the resources for each topic.

In Phase 3 teachers completed a STEBI Form A. The purpose of this survey was to establish teachers' self efficacy beliefs as science teachers and to discover in the case of these teachers, if their self efficacy beliefs determined the level of success in learning to teach by inquiry.

3.2.1 Study sample

The study sample was recruited from teachers and second level Junior Cycle students in a school in North County Dublin. Science teachers in a mixed gender secondary school were invited to participate in this study. Any teacher or student who volunteered was accepted into the study. The population and why it was chosen are described in detail in Chapter 4.3. Its purpose was to encourage the teachers to use pedagogies that would support learning by inquiry for example, student-led inquiry, learning concepts through inquiry, asking questions that promote IBSE and students working collaboratively.

Table 3.1 and Figure 3.1 outline the study showing the three phases. Phase 1 (PLC) teachers taught the physics topic by inquiry at some time during the period from January to May 2011. In Phase 2 (CoP) teachers developed and taught the biology and chemistry topics between September 2011 and May 2012. Data collection in Phase 3 took place between September and December 2012.

Table 3.1 Overview of Research Structure.

Research question: Can I change science teacher practice towards IBSE in my school?							
Phase	**Timeline**	**Type of community**	**Topic**	**Focus**	**Participants**	**Research tools**	**Information gained**
Pre-study	2009-2010	CoP		Researcher learning	Teacher/ researcher	N/A	Developed IBSE materials phase 1
Phase 1	Spring 2011	PLC	Physics	Change in pedagogy towards IBSE using externally developed materials. Teacher implementation and student use.	Students	Adapted WIHIC survey	Views of classroom environment
					Students	Spring balance pre/post-tests	Conceptual understanding
					Teachers	Phase 1 teacher interview	Views on implementation of Topic 1
Phase 2	Autumn 2011 (biology) Spring 2012 (chemistry)	CoP	Biology and Chemistry	Change in pedagogy towards IBSE using internally developed materials. Teacher development and implementation, and student use.	Teachers	Phase 2 development survey	Views on development of Topics 2 and 3
					Teachers	Phase 2 implementation survey	Views on implementation of Topics 2 and 3
					Students	Phase 2 student survey	Views on implementation of Topics 2 and 3
Phase 3	Spring/ Autumn 2012	CoP	IBL	Reflection	Teachers	Phase 3 teacher interview	Views after completion of study.
					Teachers	STEBI survey	Science teaching self-efficacy beliefs

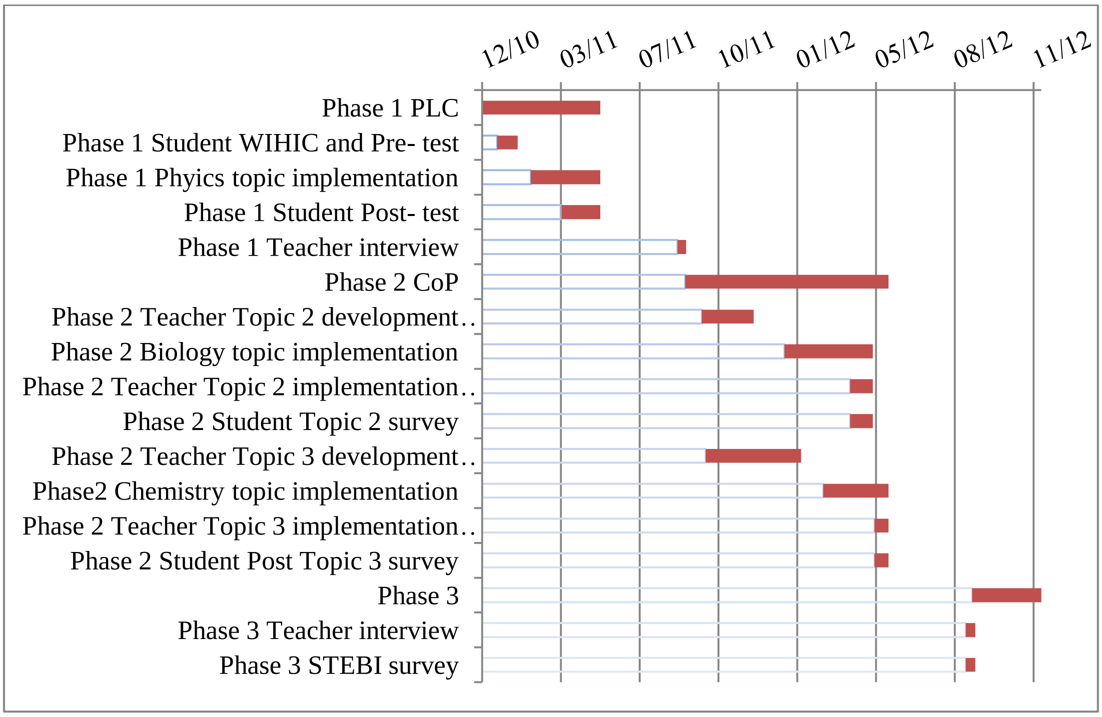


Figure 3.1 Timelines of interventions and testing in Phases 1, 2 and 3.

3.2.2 Pre-study

The pre-study phase was a formative phase for the researcher. This is where she learned the precepts and practice of inquiry firstly through professional development at a Summer school at DCU and then through a year-long community of practice where resources for Junior Science were developed in a CoP consisting of the researcher and university-based physics education researchers.

3.2.3 Phase 1

The purpose of Phase 1 was to introduce science teachers in my school to inquiry learning using prepared materials to change their practice towards IBSE. The focus, research tools and information gained are outlined in Table 3.1. The timeline of these events are depicted in Figure 3.1. In the first phase a physics topic was taught. The type of teacher community associated with this phase can be described as a professional learning community (PLC) using a coaching/mentoring framework. The teachers were given guidance so that they would teach using IBSE. This PLC corresponded to that described by Lee and Shaari (2012) in Section 2.3.3. Students were invited to complete a Likert style survey to give an indication of, firstly, their views of what is happening in the classroom and secondly, through this survey determine if they were being taught using some IBSE already. They then completed a pre-test that allowed the teacher (and the study) to benchmark the students' knowledge of the subject. The teachers then taught the topic by inquiry, giving prescribed worksheets and homework followed by a post-test. The level of understanding was then assessed by comparing the pre and post-test. The teacher then participated in a semi-structured interview to record their feelings about the topic while using the new pedagogy.

The outcomes of the PLC in Phase 1 are compared with the attributes outlined in Table 2.1. This comparison is discussed in detail in Chapter 4.3.

3.2.4 Phase 2

The purpose of Phase 2 was to consolidate science teachers change their practice towards IBSE by inviting them to participate in the development of materials to be taught by inquiry. The focus, research tools and information gained are outlined in Table 3.1. The timeline of these events are depicted in Figure 3.1.

In phase 2 biology and chemistry topics were taught. A community of practice (CoP) framework was used as outlined in Section 2.3.3. Teachers participated in the development of the topics, each bringing their experiences and expertise. This corresponded to a community of practice model (Wenger 1998). Teachers then participated in a CoP to produce materials to teach by inquiry in the classroom. In a semi-structured interview they reported their views on the content and inquiry aspects of the materials. Students and teachers completed surveys after implementation of each topic.

The CoP is compared with the framework in Table 2.2. CoP is not in itself a research tool but a framework for teacher professional development. The health or efficacy of the community is analysed in terms of participation within the community and the transformation of identity.

3.2.5 Phase 3

The purpose of Phase 3 was to evaluate if the classroom experiences of the science teachers in my school in Phase 1 and 2 of the study gave a positive outcome to the research question: "Can I change science teacher practice towards IBSE in my school". The focus, research tools and information gained are outlined in Table 3.1. The timeline of these events are depicted in Figure 3.1.

In phase 3, subsequent to classroom intervention, again a semi-structured interview was used to gather teachers' final thoughts post-study. They also completed a Likert style survey called the science teacher efficacy beliefs instrument (STEBI). The measurement of self-efficacy was used to discover if this factor had a bearing on individual teacher's success in implementing IBSE. Reflection by the researcher also provides a wider, holistic view of the study.

3.3 Research strategy

This is a case study that uses mixed methods to investigate ways to promote the use of IBSE in one school.

3.3.1 Research question

The overall research question, *Can I change science teacher practice towards IBSE in my school?,* was sub-divided into three research questions:

1. What form of professional development is appropriate to encourage teachers to understand IBSE?
2. What form of professional development is appropriate to encourage teachers to use IBSE in the classroom?
3. How do implementation experiences influence teachers' inclination to use IBSE?

3.3.2 Research approach

This case study of teaching science by inquiry to mixed ability and gender classes aimed to improve the interest and re-use of this pedagogy among science teachers. In the words of Punch (2009, p.119), “The case study aims to understand the case in depth, and in its natural setting recognizing its complexity and its context. It also has a holistic focus aiming to preserve and understand the wholeness and unity of the case”. Table 3.2 outlines the four characteristics of a case study and how the current study is aligned with this.

3.3.3 Data Collection Methods

In this section, an overview is given of the data collection methods used. A detailed description of the tools used to implement these methods is given in Section 3.4.

Survey

A number of surveys were conducted over the period of the study to describe the views of teachers and students at different time points. The objective of each survey was defined, the type of information needed and a survey method and type of question were chosen. The surveys were self-completion questionnaires. All surveys were of large format to give space for answering. Some questions were Likert-type questions and others required written answers.

Table 3.2 The four characteristics of a case study and alignment with current study. (Punch 2009, p120).

Characteristic	Current Study
It is a bounded system	IBSE experience of teachers and Junior Cycle students in one school
It is discrete	It is a case of teachers’ professional development to encourage implementation and understanding of IBSE
Holistic but focused by a research question	Takes into account experience and views of teachers and students in the context of the research questions
Uses multiple sets of data	Survey, interview, pre/post-test and narrative reports.

Likert-style surveys use a five-point ordinal scale to measure attitudes. When responding to a Likert questionnaire item, respondents specify their level of agreement or disagreement on a symmetric agree-disagree scale for a series of statements. The scaling of responses is used in most surveys and interviews for some or all of the questions in this study.

Pretests/post-tests

Conceptual development is assessed using the pre-test/post-test method. The pre-test assess students' prior knowledge and understanding of a subject. The assessments were made before and after each of the three topics taught. They are primed to learn from these tests and the teacher can correct any misconceptions that appear in their pre-tests. The questions in the post-test are similar to the pre-test questions. The improvement in answering between pre- and post-test quantifies the improvement in students' conceptual knowledge of the topic. The data on students' learning and attitudes are used in the study for triangulation purposes.

Semi-structured interviews

Minichiello et al. (1990) base the interview type on a continuum of interviewing methods by the degree of structure involved. These flow from structured interviews to focused and semi-structured interviews and lastly unstructured interviews. An interview gathers direct data through direct verbal interaction between individuals. An interview gives extensive opportunities to ask questions and probe where surveys are limited in these cases. Teachers were interviewed twice. Interview 1 took place at the end of Phase 1 and Interview 2 was conducted in Phase 3.

The interviews undertaken in this study were semi-structured. This means that although there is a pre established list of questions, some are open ended allowing the interviewee to give more complex answers (Punch 2009).

3.3.4 Triangulation of data

Much of the data are qualitative in nature, relying on the opinions of teachers, students and researcher. In this study, methodological triangulation is used where either the same method is compared on different occasions or different methods within the same study. It seeks to overcome the space limitation of this study as it took place within one culture that is the science department of one school. Triangulation of data seeks to obtain complementary quantitative and qualitative data on the same topic, bringing together the different strengths of the two methods to confer reliability and validity on the outcome (Cohen, Manion and Morrison 2011).

Rennie, Venville and Wallace (2011, p.159) found that “triangulation of theoretical perspectives exposed student learning in integrated contexts in a way that has been previously elusive because of a singular theoretical perspective that has restricted a more comprehensive vision”. It requires concurrent but separate collection of data, analysis of the two types of data and merged at the interpretation stage (Punch 2009). One example of triangulation in the current study is the interconnections between teachers’ beliefs (STEBI), their comments and students views in the inquiry class. This is important to determine the real versus the perceived situation in the classroom. Reliability and validity in research reflect multiple ways of establishing the truth (Golafshani 2003).

Reliability is concerned with precision and accuracy. If a study is reliable, it can be reproduced. Denzin and Lincoln (1994) suggest that reliability as replicability in qualitative research can be addressed as follows: Stability of observations, parallel forms and inter-rater reliability. In the current study, stability of observation was achieved by using the same questionnaire with all students and teachers on each occasion. Teacher interviews were printed in advance as a guide to ensure that each teacher answered the same questions. Parallel forms were observed by using informal conversation outside the classroom with study teachers. Inter-rater reliability was not possible as only one investigator participated in the study. Comparison between participants was only possible. The validity or trustworthiness of triangulation is discussed by Johnson and Onwuegbuzie (2004). They refer to multiple perspectives instead of multiple realities when different accounts of the same phenomenon are analysed to emphasise the subjectivity of qualitative research. They replace the word validity with legitimation in mixed methods research. Onwuegbuzie and Johnson (2006) outlined nine types of legitimation (validity) to overcome problems mix method research. Table 3.3 is taken from this paper (p. 57). An extra column is added to describe their relevance to the current study.

Table 3.3 Description of mixed methods legitimation types and their relevance to the current study.

Legitimation type	Description	Current study
Sample Integration	The extent to which the relationship between the quantitative and qualitative sampling designs yields quality meta-inferences.	Quantitative (three student surveys) and qualitative data (teacher surveys and interviews) available.
Inside-Outside	The extent to which the researcher accurately presents and appropriately utilizes the insider's view and the observer's views for purposes such as description and explanation.	Researcher not present while student and teacher surveys completed. direct quotes at all times.
Weakness Minimization	The extent to which the weakness from one approach is compensated by the strengths from the other approach.	Interviewer questioning may (unwillingly) influence subject reply. Strength of quantitative data may compensate
Sequential	The extent to which one has minimized the potential problem wherein the meta-inferences could be affected by reversing the sequence of the quantitative and qualitative phases.	All data treated sequentially.
Conversion	The extent to which the quantitising or qualitising yields quality meta-inferences.	Data convergence occurred in many cases.
Paradigmatic mixing	The extent to which the researcher's epistemological, ontological, axiological, methodological, and rhetorical beliefs that underlie the quantitative and qualitative approaches are successfully (a) combined or (b) blended into a usable package.	From and ontological perspective, researcher viewed undertaking the study to be worthwhile (pre-study) and then changing the PD focus post phase1 to CoP from PLC in the belief that teachers would, given the appropriate environment, teach by IBSE. Methodologically, interview and survey are widely used in qualitative research.
Commensurability	The extent to which the meta-inferences made reflect a mixed worldview based on the cognitive process of Gestalt switching and integration.	Changing PD from PLC to CoP.
Multiple Validities	The extent to which addressing legitimation of the quantitative and qualitative components of the study result from the use of quantitative, qualitative, *and* mixed validity types, yielding high quality meta-inferences.	Results from different sources may converge in triangulation.
Political	The extent to which the consumers of mixed methods research *value* the meta-inferences stemming from *both* the quantitative and qualitative components of a study	The assumption that a single unit can always be measured more than once violates the interactionist principles of emergence, fluidity, uniqueness and specificity (Denzin 1997, p.320).

3.4 Research Tools

In this section the tools that were used in the study to implement the methods described in Section 3.3 are discussed in detail. The description includes preparation and presentation of data, handling and treatment with respect to reliability and validity. Table 3.4 outlines the tests used for data analysis discussed in the section below.

Table 3.4 Tests used for data analysis.

Data set	Test/ query	Rationale	Numbers
Phase1			
PLC	Attributes of PLC	Success of PLC	n=6
WIHIC	Kruskal-Wallis test	Difference in student attributes by teacher (WIHIC).	111, six groups
	Mann-Whitney U	Comparing first year with second years students	111, two groups
	Descriptive %	Quantifying student opinion	111, six groups
Pre-test/post-test	Wilcoxon signed rank test	Assess conceptual development before and after Topic 1	n= 87
Pre/post	Descriptive %	Success of teacher implementation	n=87
Teacher recollection	Interview	Overview of teacher implementation.	n=6
Phase 2			
CoP	Wenger matrix	Quality of teacher CoP	n=4
Biology	Questionnaire	Improve topic development, teachers.	n=4
Biology	Kruskal-Wallis test	Difference in student attitudes by teacher	n=57
Biology	Descriptive %	Student views of study	n=57
Biology	Questionnaire	Teacher satisfaction and implementation of IBL	n=4
Chemistry	Questionnaire	Improve topic development, teachers	n=4
Chemistry	Kruskal-Wallis test	Difference in student attitudes by teacher	n=57
Chemistry	Descriptive %	Student views of study	n=57
Chemistry	Questionnaire	Teacher satisfaction and implementation of IBL	n=4
Phase 3			
Teacher recollection	Interview	Overview of teacher implementation.	n=5
STEBI	Compare with literature	Teacher self efficacy Does it affect teacher implementation of IBL?	n=4
Researcher Recollections	Note taking	How the study changed course	n=1
Assess three sets of data together	Triangulation	To confirm one outcome with three sources	

Choice of statistical analyses was based on Table 38.4, p.701 in Cohen, Manion and Morrison (2011). All appendices associated with this chapter are grouped as follows: Appendix A contains all surveys, questionnaires and interviews, Appendix B contains physics topic development of physics, Appendix C contains biology topic development Appendix D contains chemistry topic development. Appendix E contains study consent forms.

Adapted WIHIC survey

Student attitudes to their classroom environment were assessed using an abridged version of the “What is Happening in the Class?” (WIHIC) questionnaire of Aldridge, Fraser and Huang (1999). This survey has been validated internationally in many languages (Dorman, 2003). The students answer 56 Likert style questions in the survey. The response format to these questions is that described by Likert (1932) where the student has five choices on a scale from ‘strongly agree’ (SA), ‘agree’ (A), not sure (N), disagree (D) to ‘strongly disagree’ (SD). The scoring either ranks the answers positively SA to SD with a score of 5 to 1 or negatively SA to SD 1 to 5. In the current study 15 of the 56 questions were used. The choice of these 15 questions is outlined below.

The questionnaire used for this initial survey is in Appendix A (i). Taking a holistic view of the study, the researcher was aware that the teachers (comments noted before the study) were not interested in giving a full forty minute class or longer to completion of the 56 question survey. It is in the nature of a collaborative effort that consideration was given to the participating teachers concerns. The option of using an on-line survey was not realistic as computer time was at a premium within the school and not all students (in early 2011) had access to computers outside school. The shortening of the survey will have interfered with its integrity. It was not possible to use the scoring of the original WIHIC survey, but the adapted version still gives an indication of some student perceptions in the class.

The validated survey examines 7 aspects of the classroom environment. All of these 7 aspects are included in the shortened survey. These are: (1) student cohesiveness (extent to which students know, help and are supportive of others), (2) teacher support (extent to which teacher helps, befriends, trusts and show interest in students), (3) involvement (extent to which students have attentive interest, participate in discussions, perform additional work and enjoy the class) (4) investigation (emphasis on skills and processes of inquiry and their use in problem solving and investigation), (5) Task orientation (extent to which it is important to complete activities and to stay on subject matter) (6) cooperation (extent to which students cooperate instead of compete) and (7) equity (extent to which students are treated equally by the teacher) and one extra from "task orientation". The questions chosen from these sections were chosen to focus on IBSE in the class and eliminating repetition of questions.

Data were inputted to and Excel spread sheet as coded data as described above. These data were then analysed using SPSS version 20. Coded data are treated as nominal and ordinal data. Three tests were used: Kruskal-Wallis, Mann-Whitney, and Wilcoxon Signed Rank.

The Kruskal-Wallis test compares three or more non-parametric independent unrelated groups. It can also analyse samples of unequal size. It is the non-parametric equivalent of the analysis of variance test (not used in this study). The Mann-Whitney U (also known as the Wilcoxon Rank Sum test) is the equivalent non parametric test for two unrelated samples. This test analyses paired data counting the number of times there is a positive change, a negative change or no change. The Wilcoxon Signed Rank test was used when comparing two related samples, matched samples, or repeated measurements on a single sample to assess whether their population means ranks differ. This is the non-parametric equivalent of the paired I-test (Cohen, Manion and Morrison, 2011) Results of this survey are presented in Chapter 4.3.1.

Spring balance pre/post-tests

In Phase 1, the spring balance was the unit chosen for teachers' PD to demonstrate the use of IBSE in the classroom. One purpose of introducing IBSE to the classroom is to improve conceptual understanding of a topic. To demonstrate conceptual understanding of the topic, students were tested before and between 2 to 4 weeks after the topic to determine if their concept of forces improved. Pre- and post-test were developed in the Pre–study phase along with the teaching guide and the student resources. The pre- test is a series of questions outlined in Appendix A (ii). Two questions required physical measurements and the others sought to indicate their understanding of gravity. Although the test is not pre- validated, the results gave an indication of the students' progress in understanding the learning outcomes.

There were six questions in the post-test (Appendix A (ii)). One question required them to synthesise the information they had encountered/discovered during the experiment, another sought to find if they had been sensitised by the pre-test to seek an answer, three more required them to demonstrate their ability to understand graphs and a final question asked about the method used.

To be able to analyse the results it was necessary to code the data. The coding rationale is also outlined in Appendix A (ii). The results from both the pre and post-test were coded 'adequate' (1) or 'inadequate' (2) for the purposes of analysis.

The codes were used for analysis of the data in SPSS v20. "1" denoted and adequate answer, 2 an inadequate answer, 8 if the answer to a particular question was missing and 0 if no questions were answered, that is, the student was absent.

Responses to comprehension tests of spring balance topic are outlined in Table 4.5. This table shows the percentage of students who responded adequately.

The Wilcoxon Signed Ranks Test is used to compare related data sets that are not normally distributed. All pre-test results are pooled and compared with their matched post-tests. The null hypothesis is that all class results would remain the same post-intervention. The alternative hypothesis was that students would improve post intervention.

Comparing students' responses to matching questions in the pretest and the post-test seeks to elicit their change in understanding of the difference between weight and mass. The results are stratified by teacher and are presented as percent adequate response at both times. The purpose is to observe if there is an improvement in student understanding by teacher group. The validity of this data is questionable when used on its own as student numbers vary between pre and post-test but the result may be used to strengthen other arguments.

Phase 1 teacher interview

Teachers were interviewed after phase 1. The interviews – see Appendix A (iii) – were semi-structured in an effort to glean as many of the teachers' thoughts and ideas after their experiences of IBL. The intention was to create an environment of trust to produce understanding grounded in the specific classroom experience of inquiry teaching. All teachers were allotted 30 minutes for their interview, which was held in a quiet room at a time when they were available for at least one hour.

The purpose of the interview was to give teachers time to outline their views on the topic they had taught by inquiry. The teachers were not seen as repositories of answers but participants in the formation of the community of practice whose opinions were valued in the on-going production of materials to be taught by inquiry. Although the questions for both interviews were developed, they were used, as a guide to allow the respondent to elaborate on what they felt was important to them. They were asked their views of the administration and explanation of the first topic was adequate and what they would change. They were invited to give their view of the students' reaction to being taught by inquiry. Questions were asked to ascertain how they conducted the class and how organised they and the students were during the topic. Teachers were asked to describe how they would normally teach the topic.

This question was used to promote a thinking process to compare their teaching method with IBSE as part of professional development.

The interviews elicited rich, thick descriptions from teachers that gave an insight into their classroom experience. The responses of the six teachers were tabulated and used as teachers' baseline reactions to the introduction of IBSE into the classroom.

Phase 2 development survey

Teachers were surveyed by questionnaire to determine their views on the content of Topics 2 and 3 (Appendix A (iv)). The survey also served to highlight aspects of inquiry incorporated into the topic to improve their understanding of IBL and to further their professional development. Appendix A (iv) also outlines the questions posed to teachers before both Topic 2 and 3 the type of question and its rationale. This questionnaire seeks factual information and also attitudes, values, opinions and beliefs. Its purpose is not only to gain this information from respondents but also to create an awareness of inquiry learning and a motivation to use IBL alongside rather than instead of their own teaching methods.

Teachers were given the survey to complete in their own time. The researcher reviewed the completed surveys to enhance the accuracy of the account. The findings from each teacher's questionnaire was inputted on a spreadsheet and tabulated. These results are discussed in Chapter 4.4.2. (Topic 2, biology) and Chapter 4.4.6 (Topic 3, chemistry).

Phase 2 Implementation Survey

Teachers' views on the implementation of Topics 2 and 3 were surveyed after each of the topics. The information collected from these surveys was used to assess the research sub-question: How do implementation experiences influence teachers' inclination to using IBSE? They were asked to complete the questionnaire outlined in Appendix A (v), allowing the researcher to ascertain their impressions of using IBL and their students' understanding as a result of the teaching method. The questions were open to give the teachers an opportunity to give their impressions of the unit. They were asked what they did differently to their normal practice and what would they now change. They were invited to give their views of students' response to the unit, their understanding of it and if it improved their critical thinking. For example, they were asked the question: *How else do you think critical thinking could be tested?* The purpose of this question was to prompt them to think about the use of IBL. In this way we sought to encourage teachers to use IBL in other classes not participating in the study.

Appendix A (v) also outlines the rationale for the question type used. The questionnaire attempts to elicit teachers' beliefs of their students' views. Again its purpose is not only to gain this information from respondents but also to create an awareness of inquiry learning and a motivation to use IBL and in this case to be able to compare the students views with the teachers' perception of their views

Phase 2 Student Survey

Students were surveyed after implementation of Topic 2 and 3 to compare their views of their enjoyment and level of difficulty with the teachers' perceptions of students' views. The survey also asked questions to determine from the students' perspective what level of inquiry occurred in the classroom. These data were used to triangulate with the teachers views to answer the research question: Can I change science teacher practice towards IBSE in my school?

On completion of Topics 2 and 3 students also completed a survey, given in Appendix A (vi). The students' survey after both units asked questions to cross-check the validity of the teachers' answers. Three Likert style questions were included in the student questionnaire and two questions with suggested answers. Appendix A (vi) also outlines the type of question and the rationale. The students' questionnaires were more specific as they were not likely to be expansive in their answers. The questions allowed them to reflect on what they had experienced and prompted them to think about the inquiry aspects of the lessons.

Students were given the surveys to complete in class. The responses were inputted to a Microsoft Excel spreadsheet. This master sheet was then exported to nVivo 9 or SPSS 20. The frequency of the appearance of words in the student survey was determined using Vivo 9. The students' enjoyment of each topic and their perception of the difficulty of the topics were evaluated using SPSS 20 statistical tests applied are outlined in Table 3.4. The findings from these surveys are discussed in Chapter 4.3.1 and 4.4.1.

Phase 3

Teachers were interviewed in Phase 3 having participated in the CoP to develop two topics to be taught by inquiry. The purpose of this interview was to answer the research question Can I change science teacher practice towards IBSE in my school? And the three sub questions: 1. What form of professional development is appropriate to encourage teachers to understand IBSE? 2. What form of professional development is appropriate to encourage teachers to use IBSE in the classroom? 3. How do implementation experiences influence teachers' inclination to using IBSE?

The same setting as that of the first interview was used. The questions posed in this interview are in Appendix A (vii). The teachers were asked about the students' reaction to IBSE and what aspects they enjoyed. They were asked if they introduced IBSE into the study classes and other classes also. Teachers were asked if they felt

(1) the students were influenced by their attitude to IBSE, (2) if they (the students) felt challenged by it and (3) were thinking more critically as a result of the experience.

Similar to the first interview, this was considered a joint enterprise between both interviewer and respondent. The purpose of the interview was to gather feedback from the teachers about their experiences with inquiry learning, their perceptions of how the students felt about the process, to ascertain if their understanding of inquiry had improved and if they continued to use inquiry in other classes.

Of the eighteen questions, nine questions related to the teachers' perceptions of student views. Seven of the remaining questions related to their views, understanding and willingness to use IBL again and the final two related to how the teachers interacted with their colleagues. The final interview was used to strengthen the internal validity of earlier study data. This was in the form of member checking and cross-checking students reported perceptions. The interview also sought to determine if the teachers' understanding and inclination to use of IBSE had changed. The interviews elicited rich, thick descriptions from teachers that gave an insight into their classroom experience. Discrepant information was also noted as one teacher who left the study after phase 1 agreed to attend a final interview. This contrary information depicts some of the difficulties when implementing a new pedagogy.

The interviews were tabulated by teacher and by question. Chapter 4.5.1 outlines the teachers' views after completion of the three topics.

STEBI survey

STEBI was used to determine if the level of teacher self efficacy belief influenced teachers' understanding, use and inclination to use IBSE. In STEBI form A (Enochs and Riggs, 1990) self-efficacy refers to an in-service teacher's own belief in their own ability to successfully perform a specific task. STEBI also utilises a Likert scale format as described above. Within the STEBI scale, there are two sub-scales. These are: Personal Science Teaching Efficacy Belief (PSTE) scale and Science Teaching Outcome Expectancy (STOE) scale and questions do not overlap. Appendix A (viii) outlines the questions in the STEBI survey.

An example of a question in this survey is: “The inadequacy of a student’s science background can be overcome by good teaching”. A teacher with high self efficacy beliefs is likely to reply, “strongly agree” to this question.

This survey was validated by Riggs and Enochs (1990) with elementary school teachers from Kindergarten to 6th grade in the U.S. The student population was younger than the current study population with a possible overlap at age 12. Unlike the teachers in the current study the teachers were not specialist science teachers. Although the teachers in the current study were science teachers, they were not specialists in each discipline (physics, chemistry, biology) they were teaching.

Teachers completed the STEBI survey once after their final interview in Phase 3. The data were analysed using the Likert scoring system and comparing teacher results with the final scores achieved in the study conducted by Laskhmanan *et al*. (2011). Results are outlined in Chapter 4.5.3.

3.5 Development and Implementation of Activities

3.5.1. Development and Implementation of Physics Activity

Development of physics activity

The Spring Balance was the physics topic chosen for this study. It was developed before the project commenced by a CoP that included researchers from DCU, second level teachers from different schools and the teacher/researcher.

The experiment was chosen to correspond to a learning outcome in the Junior Science syllabus (DES 2003). A pre-test was designed to discover how much the student knew about the topic and to prime them to look for the answers to those questions that they were unable to answer. The language was chosen to suit the target age group. Appendix B (i) outlines the rationale associated with the pre-test questions and the experiment questions.

In the experiment, students were given the required equipment and were guided within a handout. On completion of the experiment is the students phrase the result in terms of proportional reasoning, and finally they attach a name to it: Hooke’s

Law. Appendix B (ii) outlines the elements of inquiry and language used in the classroom.

The homework set for this topic reinforced the work done in class and contained analysis to extend this work. These questions gave the student a chance to form a greater depth of understanding of the topic. Homework and analysis questions are outlined in Appendix B (iii) and (iv).

The post-test probes the retention of the knowledge gained from the experiment and students' understanding. The post-test was administered a week after the topic was completed. Appendix B (v) outlines the post-test questions.

Implementation of Physics Activity in a PLC

The physics activities were presented to seven teachers in a local school using a presentation outlining the topic and how it might be taught by inquiry (Appendix B (vi). In the presentation, the teachers were taken through each stage of the experiment and shown where the aspects of inquiry were located within the activities by the researcher. At the end of the presentation, they were given an opportunity to ask questions.

Teachers received a Lesson Plan (Appendix B (vii)) and all the resources associated with the topic: pre- and post- test, experiment, homework and analysis. The teachers then attempted to teach by inquiry. Appendix B (ii) also outlines the learning pre requisites, the verbal and experimental elements of inquiry, the language in this topic and the teachers' comments after implementation.

3.5.2 Development and Implementation of Biology Activity

Development of Biology activity

The Structure and Transport in the Flowering Plant was the biology topic chosen for this study by consensus among participating teachers. It was developed by the CoP comprised the teachers who were learning to teach by inquiry, researchers at DCU and the teacher/researcher. The teachers suggested the topics that allowed a number of learning outcomes from the Junior Science syllabus (DES, 2003) to be achieved.

Some teachers have concerns about the length of time it takes to teach by inquiry. They were asked how long they normally take to teach this topic. Their replies coincided with the timing outlined in the teaching guide. The final draft incorporated the suggestions of teachers and researchers. Appendix C (i) outlines the elements of inquiry, the language used in the classroom and teachers comments.

A number of changes were made to the implementation of the topic from feedback received during the teachers’ interview after Topic 1 (see Figure 3.1 for timing of this interview). Both teachers and students were unhappy with the quantity of paperwork associated with the lesson first topic. To address this issue the level of paperwork was decreased. A pretest was not included. Instead, priming questions were added to the text of the teachers' guidelines (outlined in Appendix C (ii)). No homework was given to the teachers. A post-test was created but the teachers were allowed to choose if they wished their students to take it. I (the researcher) made the decision that it was more important that the teachers should try teaching by inquiry without having the pressure of a post-test to avoid teachers teaching to the test. Teachers might decide not to use inquiry learning to make sure their students perform well in the test.

On completion of Draft 1 of the teacher’s guide it was given to researchers in DCU for their comments. All feedback led to a second draft, which was shown to the teachers. The teachers were asked to read this draft and to complete Phase 2 surveys. Phase 2 development survey is outlined in Appendix A (iv). The final draft (Draft 3) was subsequently developed (Appendix C (iii)).

The four teachers’ views of this draft are in Appendix C (iv). There were a number of aspects that they felt should be changed. I took the view that they needed to have the confidence to take the teaching guide and use it as their own. To that end I incorporated their suggestions into the final draft.

Implementation of Biology activity

Teachers were given the mind map (Appendix C (v)). The mind map template was created by the School Development Planning Initiative (SDPI). The details for this particular topic were generated by the researcher. The teachers also received a Power Point presentation (Appendix C (vi)) and the final draft of the teaching guide.

They were also given the physical resources (plants, seeds, stereoscopes, sensors and hair dryers), Appendix C (vii). It was stressed that they should take the teaching guide and incorporate their own teaching into this while using IBL. It was emphasised that they should focus on the inquiry aspects highlighted in red. They did not receive any extra paperwork in the form of a student guide or homework.

3.5.3 Development and Implementation of Chemistry Activity

Development of Chemistry activity

The same community of practice that developed Topic 2 developed the chemistry topic. This topic of chemical bonding was chosen, as it did not require a laboratory component. The intention was to emphasise active thinking and to demonstrate to both teacher and student that inquiry did not rely on the laboratory. It was also chosen as the participating teachers found that students struggle with this topic, as it is abstract and difficult to teach. They felt that trying a new approach might help them.

As with the biology topic, it was insured that the learning outcomes for chemical bonding in the Junior Science syllabus (DES, 2003) were met.

This is students' first school exposure to the topic. The abstract nature of this topic requires it to be taught using a model outlined in the Junior Certificate syllabus. The prerequisites for introducing this topic were that students be familiar with the Bohr model of atomic structure, to know the atomic number and mass of the first 20 elements and be familiar with the periodic table.

Aspects of inquiry based learning in the unit are outlined in Appendix D (i). Priming questions were added to the text of the teachers' guidelines (outlined in Appendix D (ii)).

When draft 1 of the teacher's guide was complete it was given to researchers in DCU for their comments. Their comments were noted and the next draft was amended to reflect the suggestions. These suggestions improve the scaffolding around which students can learn by inquiry for example putting in the tentative rule "no reaction when shell is full" is essential for students to proceed to bonding.

Worksheets and a post-test were included as the teachers felt that they regretted not having any during Topic 2.

The teachers were shown the second draft of the chemistry topic. As was discussed earlier, they were asked to complete the Phase 2 development survey. This is in Appendix A (iv). Appendix D (iii) is the chemistry teaching guide that was shaped by participating teachers' comments Appendix D (iv).

A teacher in the school, who was not participating in the study, explained how she engaged her students so that they might understand on a macro level what was happening at the sub-microscopic level. She divided her class up into different groups. They had labels that made them either ions for bonding or covalent molecules. She set the "disco scene" and explained ionic bonding as those who flitted from partner to partner" and covalent "couple in the corner who were not interested in anyone else". This was incorporated into the teaching guide.

Implementation of Chemistry activity

A mind map (using the same SDPI template used previously) was completed (Appendix D (v)) to give direction during the production of the teaching guide. The level of detail meant that teachers would have sufficient resources to teach the class. A Power Point presentation (Appendix E (vi)) to use as a summary for their students on completion of the topic was given to teachers along with the teaching guide. They were also given the physical resources (magnetic rings or paper and blue tack (Appendix D (vii)) . Once again it was stressed that they should take the teaching guide and incorporate their own teaching into IBL. It was emphasised that they should focus on the inquiry aspects highlighted in red.

3.6 Ethical Considerations

Informed consent was obtained from parents and teachers. The methods employed are tried and tested so it was in the students', teachers' and researcher's interest. None of the results are available or traceable to anyone other than the researcher or supervisors. The possibility of the results being negative, although remote could be remedied before the examination year as the study took place in year one and two of the Junior cycle.

Six teachers agreed to participate in the study. They received consent forms to indicate their agreement to participate in the study (Appendix E (i)). They also distributed consent forms to the students (Appendix E (ii)) that were to be signed by students' parents and returned to the teacher. This outlined the nature of the study, the confidentiality of the results and the right not to participate without penalty.

The researcher collected data from teachers and the teachers collected student data. The researcher was unaware of the identity of the students to maintain their anonymity. The questionnaires and teaching guide were given to the teachers two weeks before commencement of the topic. This was returned within a week of finishing. They were then coded for analysis. Teacher confidentiality was preserved during the study where necessary. The researcher did not share the individual view of any teacher with the other participants. They may themselves have chosen to speak to each other. In this document all teachers are referred to as "she" to confer anonymity.

3.7 Limitations of the study

The limitations of the research are due to the subjective nature of the study. People (both student and teacher) like to please and so their answers could be influenced by the need to please or conform hence the need for multiple research tools both qualitative and quantitative to either corroborate findings or reveal discrepant data. The distance in time between delivery of each of the topics was also a problem. This disrupted the continuity of the study and so the desired effect of improving critical thinking. Using statistical packages also causes issues: researchers may feel distanced from their data with too heavy a focus on coding and retrieving that removes data from context. The results correlation may not imply cause (Creswell 2003).

The first topic was found to be difficult for the age group who were in the study. Their graphing skills were inadequate that diminished the usefulness of the experience.

It is not possible to generalise from a case study. In allowing teachers to choose what resources and tests they would implement, this weakened the study as there were no student learning outcomes. It is impossible to assess the impact it would have had on teacher development if these tests were imposed on them. The development of more topics that were more evenly matched in terms of difficulty would have enabled a view of teacher and student progression. Measurement of teacher self efficacy at a few time points during the study may have shown a change as they struggled and then succeeded with the pedagogy. The use of reformed teaching observation protocol may have given a more objective view of what was happening in the class. On the other hand the study has given an insight of the strengths and pitfalls associated with attempting to introduce IBSE in my school. In terms of execution, the adapted WIHIC survey was only given before teachers implemented the IBL materials while the STEBI survey was only given on completion of classroom the material. With hindsight, more could have been gained from the study if these surveys had been given both before and after.

3.8 Summary

This research uses a case study approach using mixed methodology for data collection. The study encompasses teachers and Second level Junior Cycle students in a school in North County Dublin. Table 3.1 and Figure 3.1 outline the time line and interventions in the study. Phase 1 emphasised the use of pre developed materials to introduce IBL to the science classroom. Phase 2 places emphasis on teachers developing materials with other teachers to teach by inquiry that they would subsequently use in the classroom.

In the first phase a physics topic was taught. The type of teacher community associated with this PD phase can be described as a professional learning community (PLC) using a coaching/ mentoring framework. In phase 2 biology and chemistry topics were taught. A community of practice (CoP) PD model was used in phase 2. The teachers all participated in the development of the topics, each bringing their experiences and expertise. In phase 3, subsequent to classroom intervention, teachers participated in another semi-structured interview to gather their final thoughts post-study. They also completed a Likert style survey called the science teacher efficacy beliefs instrument (STEBI). Reflection by the researcher also provides a wider, holistic view of the study.

Much of the data are qualitative in nature, relying on the opinions of teachers, students and researcher. In this study, methodological triangulation is used where either the same method is compared on different occasions or different methods within the same study.

This study suffers from a lack of inter-rater reliability as only one investigator participated in the study. Comparison between participants was only possible.

The principles of development and implementation of the physics, biology and chemistry topics for classroom activities are outlined in this chapter. Ethical issues were discussed.

The researcher was unaware of the identity of the students to maintain their anonymity. In this document all teachers are referred to as “she” to confer anonymity.

The limitations of the research are due to the subjective nature of the study. The distance in time between delivery of each of the topics was also a problem. This disrupted the continuity of the study and so the desired effect of improving critical thinking. Using statistical packages also causes issues: researchers may feel distanced from their data with too heavy a focus on coding and retrieving that removes data from context. The results correlation may not imply cause.

Study results are outlined in the next chapter followed by the conclusion and study summary.

Chapter 4. Results

4.1 Introduction

In Chapter 3, I described the research approach, methods, tools and analysis for the results outlined in this chapter.

The structure of this chapter is as follows: findings of Phase1 (PLC), Phase 2 (CoP) and Phase 3 (reflection on Phase 1 and 2 interviews and surveys in conjunction with those collected in this phase).

The purpose of this study was to discover if, with the necessary resources and using a CoP approach, teachers would in a second level school incorporate structured/guided inquiry in the science classroom. My research question is as follows:

Can I change science teacher practice towards IBSE in my school?

This research question was sub-divided as follows:

1. What form of professional development is appropriate to encourage teachers to understand IBSE?
2. What form of professional development is appropriate to encourage teachers to use IBSE in the classroom?
3. How do implementation experiences influence teachers' inclination to use IBSE?

To achieve the goals of the study, there were three classroom interventions between Phase 1 and 2 and a period of reflection (Phase 3). The teachers when participating in Phase 1 are described as a PLC and in Phase 2 a CoP. Descriptions of PLCs and CoPs are outlined in Chapter 2. Briefly, a PLC is an "expert lead" community and a CoP is a "member driven" community.

The teachers then attended a final interview (Phase 3 teacher interview). The purpose of this was to find their views on the use IBSE, what they perceived their students' views were of learning by inquiry, if they felt their students were thinking critically and if they intended to continue to use IBSE after the study. Figure 3.1 is a Gantt chart of the timelines of interventions and testing in Phases 1, 2 and 3.

4.2 Pre-study (How the research question evolved)

I included this pre-study as it outlines for the origins of the study and how the organisation of the participants eventually influences the framework of the current study. This first CoP evolved from a Summer School that took place at DCU the in Summer 2008. Teachers were invited to participate in learning to teach by inquiry and to develop suitable materials for use in the classroom. In the following school year (2008 to 2009), three teachers, two postgraduates and one researcher met twice a month to develop several topics. One of these, The Spring Balance, was used in Phase 1 of the study.

4.3 Phase 1 Professional Learning Community

Of the eight science teachers on staff, five were teaching first year science for the year in question and agreed to participate. A sixth teacher joined the study who was teaching a second year class. This second year class had not completed the proposed first inquiry topic. Table 4.1 outlines the number of years experience and enjoyment of teaching science subjects.

After the success of the CoP at DCU, I was enthusiastic to introduce my colleagues to inquiry based learning. Phase 1 of this study was the first attempt to answer my research question: Can I change science teacher practice towards IBSE in my school?

In this PLC model, (Phase 1) I took on the role of the expert and the teachers took the role of learner. This community of teachers and teacher/ researcher can be described as a PLC because the teachers were involved in professional learning aimed at enhancing their professional learning identity (Lee and Shaari 2012). This PLC adopted a structured “top down” approach where only one of the teachers had used inquiry learning in the classroom. All of the teachers appeared enthusiastic to try the first topic chosen to teach through IBL. A meeting was held to provide an introduction to inquiry learning. This meeting gave an opportunity for the participants to discuss their understanding of inquiry and an invitation to continue to discuss the pedagogy with the researcher/teacher while implementing it in the classroom.

Table 4.1 Participating teachers' experience.

	Qualified to teach	Preferences in teaching Science
T 1	Science, chemistry, biology	Prefer chemistry, biology
T 2	Science, math's, physics, biology	No Preference
T 3	Science, computers	Happy about most of it.
T 4	Science, physics	Happy
T 5	Science, biology	Happy
T 6	Science, math's, biology	Prefers biology and chemistry, strong dislike of physics.

In this section I will examine the qualities of a professional learning community developed in this phase. The purpose is to put into context the role of the teacher and researcher in terms of professional development. The differences between a PLC and CoP are discussed in Chapter 2.3.3.

The points below outline the qualities of a professional learning community (see Chapter 3).

1. *The collegial and facilitative participation of the principal who shares leadership and thus, power and authority through inviting staff input in decision making*

The school Principal and the board of management gave permission for the study to take place. Although the principal did not have any active part in the study, he facilitated the promotion of the study through his positive encouragement. At the next level, although I was steering the study through my experience at DCU, the teachers had freedom within their own class to implement the first topic without intervention after the first meeting. They were free to seek advice informally at any time.

2. *A shared vision that is developed from an unswerving commitment on the part of staff to students' learning and that is consistently articulated and referenced for the staff 's work*

This commitment to students was evident from the beginning of Phase 1 (outlined below). Many questions and comments made by teachers related to student welfare and learning outcomes.

3. *Collective learning among staff and application of the learning to solutions that address students' needs*

The purpose of the study was for the teachers to learn to use IBL as a pedagogy alongside the techniques that the teachers already used. This was the first topic where five of the six teachers engaged with the IBL pedagogy.

4. *The visitation and review of each teacher's classroom behavior by peers as a feedback and assistance activity to support individual and community improvement*

Feedback from the teachers and assistance from me were central to the study. The importance of listening to their experiences, acting on their fears and remedying their issues was central to insuring the success of implementing IBL at a whole school level. The interview after Topic 1 gave voice to any of their concerns.

5. *Physical conditions and human capacities that support such an operation*

The PLC was a community within a community that already existed. All teachers who participated within this sub-community did so voluntarily and supported the challenge to teach by inquiry. They were given the physical resources and skills to take IBL into the classroom.

The community gave a structure to the introduction of IBL to first year classes at the school. This was the teachers' first encounter with teaching by IBL for all but 1 teacher. It was an appropriate model, as they required assistance to implement the pedagogy. I, as the researcher, gave guidance to the teachers. The model was successful in that the teachers had a point of contact for their professional development available to them formally and informally if they encountered difficulties. All teachers as evidenced by their responses in the interview after they completed the topic did have a certain understanding of IBL as discussed later in Table 4.6.

My role within teacher professional development in Phase 1

I was the point of contact for the teachers' professional development in the professional learning community.

At the time of the first meeting with the teachers, I noted that there was some confusion regarding different types of inquiry. The teachers appeared to assume that all inquiry was now open ended and also had preconceived negative opinions of this approach. T 1 noted, "[this method] would disadvantage pupils who used inquiry learning for investigations". T 5 said, "You have to give kids direction- they don't read from a hand-out... Discovery learning is a disaster". In Figure 4.1 additional teachers' comments are presented.

T 1: "It would never work, it would take too long".

T 1: "Junior certificate investigations run this way would disadvantage pupils as all other pupils around the country would have help".

T 3: "What *is* inquiry based learning?"

T 5: "not telling them anything at all" leads to confusion disillusionment and disengagement".

Figure 4.1 Teachers' concerns in my school after the introductory seminar.

It was disappointing to find that the teachers' comments were so negative towards inquiry learning. One teacher even admitted that she "hated" physics. Nonetheless, she was still willing to teach Topic 1 that was physics. The teachers' understanding of inquiry was that they were required to let the students investigate without any guidance. This was not the beginning I had expected coming from the positivity of the CoP at DCU. The only positive aspect associated with this negative sentiment is that the teachers were confident and honest enough to voice their true opinions. In describing this confusion, Rogoff (1994, p.219) observed, "[teachers'] issues are based on coming to understand that [new] practices embody a distinct and coherent philosophy of learning". Rogoff also observes that teachers were experiencing "transformation of participation" that is not a transmission of knowledge but acquisition of knowledge by oneself.

After the initial meeting, teachers concerns were addressed by providing clarification on differences between open and guided inquiry. It was emphasised that they were to guide the students through questioning and were allowed to explain the handouts being used. It was also noted that teachers should embed the inquiry approach in their own teaching methods.

4.3.1 Phase 1 Adapted WIHIC survey

In order to gauge the students' initial perception to their classroom environment so that their progression throughout the study could be benchmarked, they were asked to complete a survey "What is happening in the class? This would serve as a starting point to establish a baseline for inquiry leaning in the classes.

The students (n=111) were asked to complete the adapted WIHIC survey given in Appendix A (i). Table 4.2 describes the aspect of classroom environment that was investigated. Classroom characteristics are discussed in Chapter 3.4.

In general, students' responses were positive towards all classroom environment traits. Most students in all questions either were neutral, agreed or strongly agreed with the questions posed suggesting a positive classroom environment. The results showed that of the 111 students surveyed, 90 felt that they worked well or very well with other students in all teacher groups. This demonstrates a high degree of perceived cohesiveness among these students. In Table 4.2 it can be seen that there was a significant difference in response between classes. T1's class responded to Question 1 "I work well with other class members" less positively than other classes, although there was no difference in responses to Question 2 which is the other question associated with student cohesiveness.

Student perception of task orientation, cooperation and equity in the class was high. These points suggest that students may be receptive to the new pedagogy as they were well organised individually and happy in their environment. Students replied that they were neutral or disagreed with statements of cohesiveness, teacher support, involvement and investigation. It is possible that this lack of cohesiveness and involvement was an artifact of common place teaching employed by the teachers at that time. Their perception of teacher support may have been due to their recent arrival in secondary school from primary school where the teacher's role is more "hands on".

Table 4.2 Comparison of responses to: "What is happening in the classroom?" survey across six classes.

Classroom environment trait	Question	Median Response *
Cohesiveness	I work well with other class members	**5, p= 0.023**
Cohesiveness	I help other class members who are having trouble with their work.	3, p=0.485
Teacher support	The teacher moves about the class to talk with me.	3, p=0.988
Teacher support	The teacher's questions help me to understand.	4, p= 0.208
Involvement	I give my opinions during class discussions.	3, p=0.164
Involvement	I ask the teacher questions.	3, **p= 0.017**
Investigation	I am asked to think about the evidence for statements.	4, p= 0.315
Investigation	I carry out investigations to answer questions that puzzle me.	3, p=0.068
Task orientation	I know the goals for this class.	4 p= 0.119
Task orientation	I pay attention during this class.	5, p=0.517
Task orientation	I try to understand the work in this class.	5, p= 0.583
Cooperation	When I work in groups in this class, there is teamwork.	5, p= 0.273
Cooperation	I learn from other students in this class.	4, p= 0.239
Equity	I receive the same encouragement from the teacher as other students do.	5, p= 0.441
Equity	I get the same opportunity to answer questions as other students.	5, p=0.335

* The median response is the "middle" response that is half the data is above it and half below it and is appropriate for ordinal data (Cohen, Manion and Morrison 2011 p. 701). $p < 0.05$ denotes statistical significance. Null hypothesis is that there will be no difference in student opinion across the classes.

Forty percent reported that they often or very often helped others who had trouble with their work. A similar number (thirty five percent) sometimes helped other students. There was some variation in the perception of the teacher moving about the classroom. It was my aspiration that the introduction of IBL where cooperation was central, would bring about a change in this level of interaction and so that the students would have a better classroom experience.

More than sixty per cent of all students in each class thought that their teacher's questions helped them understand the lesson. This is a central component of IBL. This would suggest that this positive perception of the learning environment in the current study would contribute to an effective inquiry classroom. Oliviera (2010) reported that student centred questions prompted larger and more articulated student responses, prompted a higher level of student thinking and positioned students as complementary experts and encouraged students to conduct authentic investigations. According to Oliviera (2010, p.445), "teachers treated their students as complementary experts (i.e., individuals whose prior experiences conferred them a certain level or degree of expertise that complements the teachers' scientific expertise). In doing so, teachers' questions served to legitimize students' oral contributions as well as their participation in classroom inquiries".

"I ask the teachers questions" is a question that determines the students level of involvement in the class. The mean rank for class 6 (the second year class) was the lowest and two students very seldom asked the teacher any questions.

In class one, (second lowest mean rank) four students seldom asked the teacher questions. This was balanced in this class by a large number of students who said they often ask questions, thus improving the median value. It may be that older students ask less questions or it may be a teacher effect. Figure 4.2 depicts the responses of students to the question "I ask the teacher questions". The responses are grouped by teacher. This question indicates the student involvement in the class. Only 15 of the 110 students who responded stated that they asked their teachers questions very often. In Phase 2, teachers begin to encourage students to ask questions as they begin to better understand IBSE. The median values across all groups for this question was that is they neither agree nor disagree.

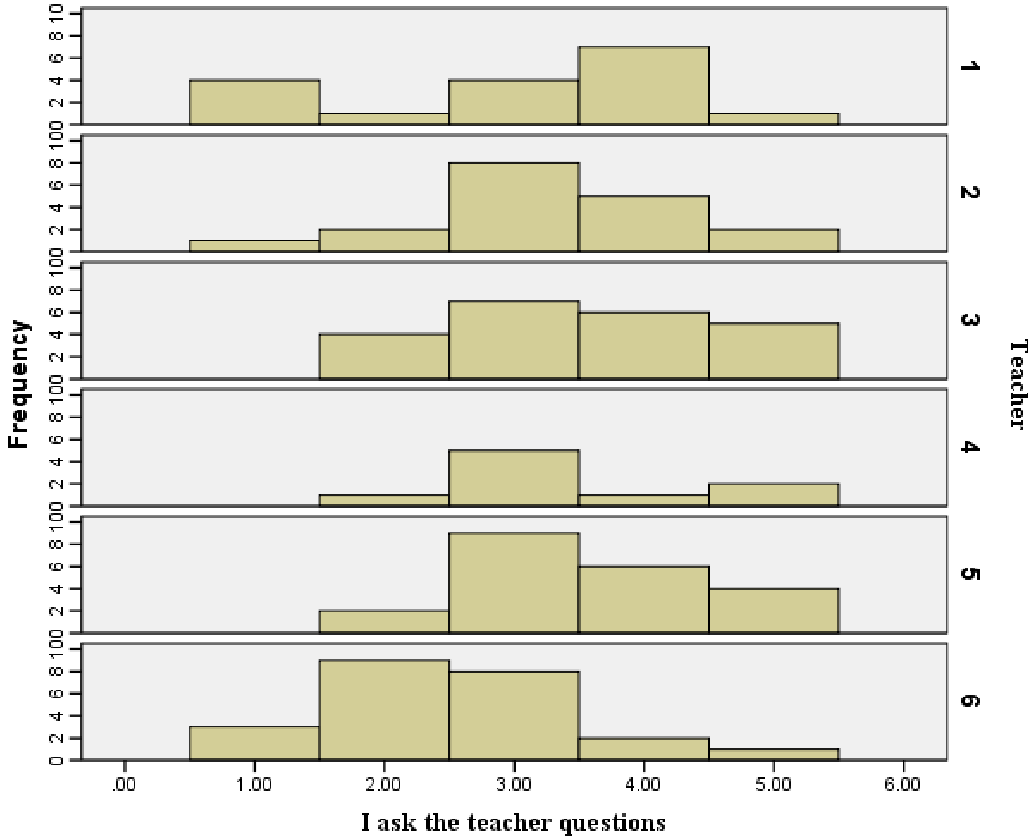


Figure 4.2 Diagrammatic representation of the responses to "I ask the teacher questions". Teacher 6 taught the second year class.

The second year students (n= 23, T6) asked questions less frequently than their first year counterparts (n= 87). This response was analysed using the Mann-Whitney U test for non parametric data. The median value of the first year response was 3 on the Likert scale ('sometimes asked questions') whereas the median value of the second year response was 2 on the Likert scale ('seldom asked questions'). The distributions were significantly different, $p<0.001$. The null hypothesis states that all classes would respond similarly to each other. The second years asking fewer questions does not indicate what type of questions were asked by either group of students. It is not therefore possible to determine if any less inquiry was happening in the second year classroom, only that fewer questions were being asked. In Phase 2, students complete surveys after Topic 2 and 3. One question was designed to discover what type of questions they asked.

Many students (n=59) across all teaching groups felt that they were asked to think about the evidence for statements made in class (Q7). This is an important point in terms IBL and indicated that teachers already used some elements of inquiry in the class without realizing it. Thinking about the *evidence for statements made* also relates to NSEC Guide for Teaching and Learning (2000) "learners provide evidence which allows them to develop and evaluate explanations".

When asked if they carried out investigations to answer questions that puzzled them, the class of T4 answered more positively than other classes. T4 is the only teacher in the group who stated she had taught by inquiry previously. Given that this was the first time that all but this one group were exposed to inquiry learning this result was to be expected.

Under the heading of task orientation, approximately one fifth or less of students in each group reported that they did not know the goals of the class often or almost always. This may have impacted students' enjoyment of their work and so may have had negative impact on student experience. When students are no aware of class goal, they would find it difficult to achieve learning outcomes.

More than eighty percent of students said that they "try to understand the work in class" often or almost always. This positive attitude is of use in an IBL class as critical thinking (trying to understand) is central to its implementation. In the main, students responded positively to these questions. When asked if they received the same encouragement as other students do, the results were positive indicating a positive classroom dynamic.

Two questions in the survey refer to *investigation.* These were: "I am asked to think about the evidence for statements" and "I carry out investigations to answer questions that puzzle me". The median response to these questions was "agree and strongly agree" respectively thus suggesting that there was some level of inquiry in the classroom prior to the intervention. (The median is useful here as it describes the middle point of the responses. The number of responses is equal above and below this point.) This finding was encouraging as although five of the six teachers indicated that they had never have formally taught by inquiry. It appears they had incorporated some aspects of it into their teaching thus possibly making it easier for teachers to adopt IBSE.

In summary, the students had a positive perception of their learning environment, asked questions of their teachers, were asked to think of evidence of their statements. Few students reported that they carried out investigations to answer questions. They knew the goals of the class and thought about evidence of their statements. It appears from this classroom environment from this survey that the conditions were adequate to introduce IBL into these students' classroom and to achieve the goals of the study.

4.3.2 First inquiry experiences: The Spring Balance

The 'Spring Balance topic' had four main components a pre-test, guided handout, homework task and post-test as described in Chapter 3.5. Students completed this unit over 8 classes. Detailed description of the Spring Balance pre- and post-tests are in Chapter 3 (tests are in Appendix A (ii)). The students' responses to these tests were characterised as adequate or inadequate based on the validity of their answer within the context of their level and understanding. In this section the students' results of the pre- and post- test will be discussed. The teachers' view of the topic after it was completed and their views of the students' perception of the topic are given in Section 4.3.3.

Both pre- and post- test question 1 (Table 4.3) refer to measuring the length of a spring. Students would have had many opportunities between the pre- and the post-test to complete this task. The response rate to the question declined from 88% of the population to 57%. The adequacy of the response fell from 85% to 27%. Although visually (they were presented with a picture the first time) most students understood the question, many had difficulty understanding a more generalised non-visual version.

Pre-test questions 2, 3, 4, and 5 sought to find out what the student knew about mass, weight and gravity. Only one third could adequately tell the difference between weight and mass. Thirty seven percent had an understanding that gravity was less than on earth. Almost equal proportions gave adequate responses to pre-test "What would happen if you put a mass on the spring shown in the diagram?" and "What is the force called that drags the spring downwards?" The proportion of students who answered questions about the difference in gravity on earth compared with the moon increased approximately 12 percent. Many still had difficulty post topic in grasping the difference between mass and weight. Eighty eight percent of students, who understood that gravity was less on the moon by a factor of 6, explained this by responding that the *mass* decreased by a factor of 6, not the *weight*.

Table 4.3 Responses to comprehension tests of spring balance topic.

Question	Valid % adequate response
Pre1. In the diagram there is a picture of a spring. Measure its length and write the answer underneath it.	85
Pre 2. What would happen if you put a mass on the spring shown in the diagram?	66
Pre 3. What would be the difference if you set this up on the moon?	37
Pre 4. What is the difference between mass and weight?	33
Pre 5. What is the force called that drags the spring downwards?	64
Post 1. Using the experiment you have just finished, how would you find the mass of a set of keys?	51
Post 2. When measuring the extended length of a spring, does it matter if it is measured from the top of the spring	27
Post 3. If the gravity on the moon is 1/6 of that on Earth, what would the weight of a 60g object be on the moon?	49
Post 4. Where on the graph would you place a mass of 10g on the graph above?	33
Post 5. Explain why do you think the graph above levels off?	19

Question 1 in the post-test asked the student how they would find the mass of a set of keys using the experiment they had just finished. Only half of those who answered the question responded that they would use the spring balance to find the mass. Another eighteen percent responded that they would put the keys on a balance to ascertain the mass. There were no follow up open-ended questions to discover the reasons for their answers.

Questions 4 and 5 in the post-test (Table 4.3 above) is concerned with constructing and understanding information from a graph. 89 students (of 116) drew the graph. 46% of the 116 students answered the questions associated with the graph. Of the three questions 19 to 33% of the responses were adequate. Adequacy of responses is outlined in Appendix A(ii). Teachers reported that students had difficulty with graphing element of the topic. This is discussed later in Chapter 4.3.4.

Both pre-test Q3 and post-test Q3 seek to find out what the student knows about gravity on the moon. Table 4.4 outlines the responses to these questions by class group. Appendix A (ii) outlines how valid responses were determined.

Table 4.4 Change in students' responses to questions that would elicit their understanding of the difference between weight and mass.

	Pre-test Q3 (n)	Pre-test (%) adequate response	Post-test Q3 (n)	Post-test (%) adequate response
T 1	14	29	17	71
T 2	15	20	12	83
T 3	18	78	17	47
T 4	9	67	9	44
T 5	16	38	10	80
T 6	13	69	23	70

Although there is an apparently striking improvement in the results of three student groups, the results of two other student groups declined while one stayed the same. Using the Wilcoxon Signed Ranks Test (data not normally distributed), using students' pooled results, without stratifying by teacher group there was no significant difference between pre- and post- test results. The null hypothesis is that all class results would be the same. The alternative hypothesis was that students would score post intervention. These results are discussed below in terms of the teacher's view of this topic (Chapter 4.3.3)

In terms of my research question: Can I change science teacher practice towards IBSE in my school? Poor student performance is unlikely to encourage teachers to implement the method or for students to be interested in being taught this way. The students' ability to visualise spring measurement post- test was poor. There was no improvement in their understanding of the concept of mass versus weight and the students' understanding of gravity being different on the moon was varied from class to class.

4.3.3 Phase 1 Teacher Interview

This section outlines the teachers' views of IBL after implementation in the classroom. A discussion of how their view changed over time will take place in Phase 3. The teachers' reaction to the *Spring Balance* topic was mixed. Their reaction was clouded by the necessity to manage the consent forms, coding and tests associated with the research side of the topic delivery. T1 commented, "Codes instead of names caused confusion". She went on to say "they were confused before we even started because we were giving out so much paperwork". All other teachers echoed this view.

Teachers' perceptions of teaching by inquiry and their experiences of teaching the physics topic were quite varied. T1 indicated that they perceived inquiry to be about "Leading questions to figure it out for themselves". T4 thought it was [to] "lead them in the right direction". T5 said she was "still not clear", although she did say that she "just let them at it". This is a common misconception as according to Banchi and Bell (2008) "teachers sometimes believe that in order for students to be engaged in inquiry oriented activities they need to be designing specific investigations from scratch and carrying them out on their own". Teachers also perceived inquiry to be open inquiry and did not appreciate the spectrum of inquiry from structured inquiry to open inquiry. Before the next phase of the study, it would be important to make sure that teachers had a better understanding of the use of

IBSE. CoP was considered as a framework for implementation of IBSE that created a strong support system for implementing change (Finkelstein and Pollock, 2005).

Table 4.5 outlines the teachers' comments on their opinions of inquiry. This information was taken from the Phase 1 teacher interview. Comparing the views expressed by teachers 1 and 3 of what was meant by inquiry and how they implemented it in the classroom; they both placed too much emphasis on not giving the students any information thus leaning towards *[open inquiry]*. T1 commented, "I tried to bite my tongue a lot...and let them figure it out". T3 felt that "I froze, totally lost my natural self". T2 still had difficulty grasping what was required and did not use the prescribed materials.

T4 expressed an understanding of inquiry learning and implemented it. T5 did not appear to engage with the process. She responded that she did not understand inquiry and did not intervene in the classroom. She became disenchanted with the implementation of inquiry and did not participate in delivering Topic 2 and 3 although she did participate in the outside class portion of the study, developing the topics and interviews.

In the literature there are reports of challenges in delivering inquiry effectively due to misunderstandings of the methodology (e.g. Kirschner Sweller and Clarke 2006). Harris and Rooks (2010) explain that inquiry learning must take place in a framework of pre-existing knowledge, "The manner in which an inquiry classroom can be managed effectively may depend on students' familiarity with science and prior content knowledge, teachers' familiarity and comfort with inquiry instruction".

What teachers felt they should achieve (open inquiry) and what was expected of them (structured/ guided inquiry) caused confusion among teachers leading T5 to leave the study.

Table 4.5 How teachers view what teaching by inquiry means and how they implemented this during Topic 1.

Teacher	**Teaching method during topic 1**
1	Open inquiry. “I just ‘shut up’ and let them figure it out. Lead them in the right direction. Actually less work [for me]. I tried to bite my tongue a lot and let them figure it out”.
2	“Very similar....”..
3	“[I asked them] Why, why, why? I froze. Totally lost my natural self”.
4	“I had to tell them. With some I had to guide them”.
5	“Let them at it, went around making sure all the pages were filled out”.
6	“I taught them the graphs beforehand. I did less feeding”.
Teacher	**Teachers’ view of what inquiry meant after Topic 1**
1	“Leading questions to figure it out for themselves. Lead them in the right direction”.
2	“I don’t think I could break it down”.
3	“Introduce a topic. Help them to a certain degree...and you pose questions and relate to everyday life”.
4	“A student is given something and they have to think, observe and do it. And they can make sense of the result”.
5	I’m still not clear, not clear at all.
6	“I think giving the students some knowledge and letting them figure it out for themselves with a little bit of help”

Table 4.6 outlines a summary of teachers' feelings about their classroom experience and graphing. T3 felt "restricted", T5 "felt it too long and I felt I had a version towards discovery learning. If I was to do inquiry learning for everything...I'd never get it done". It was impossible to dislodge this belief from this teacher's mind. Even at the end of the three topics, she still spoke in terms of discovery, not guided inquiry. My perception for T5's resistance to change is further discussed in Phase 3. This view corresponded with those of teachers in a study of McRobbie and Tobin (1997) who found that teachers wanted to "cover the work in the most efficient way possible" implying that inquiry learning required too much time to complete.

Table 4.6 Teachers' feelings about the classroom experience and graphing skills.

	Teacher's experience in the classroom	**Graphing**
1	"There was a certain level of disorganisation"	"And when I was doing it with one person ... I felt I needed to chop myself up into 24 piece's
2	"Had to give them guidance"	[No comment]
3	"Restricted"	"I spent a lot of time teaching them graphs".
4	"The group work was really, really positive. They found it difficult to write They ...hadn't had that practice before hand".	"They struggled with the graphs".
5	"I felt I had a version towards discovery learning. **If I was to do inquiry learning for everything. I'd never get it done".**	[No comment]
6	"More organised"	"I taught them the graphs beforehand"

Four of the six teachers commented on the graphing aspect of the topic. They saw the need to help the students so that they would succeed. McDermott, Rosenquist and Van Zee (1987) discussed the difficulties that they have connecting graphs to physics. T6 did help her class and this made a difference in their ability to draw and interpret graphs. The students of teachers 1 to 5 did not enjoy the physics module. Their ability to graph was quite weak which may have influenced their view of the topic.

4.3.4 Teachers' views of students view of Topic 1: Physics

Teachers were confused by the introduction of guided inquiry as outlined above. In this section the teachers' perceptions of the students' views are discussed.

When teachers reported on students' experience of the topic their reaction was mixed. Three teachers felt their students were so mired by the research administration surrounding the topic that they would forget their codes (unique number for each student that would identify them without revealing their identity). This was compounded by the duration of the topic. One teacher circumvented this problem by writing the students' names in pencil on the different handouts (T3).

T1 remarked that "Especially when you have a mixed ability class and you have more, weaker students in the class than, let's say, high fliers then they get confused really easily, even when you're giving out, [the] coding (that is the code that will identify the student in the study) stated let's say. They don't get it". T2 also commented not only on the unwieldy nature of the study administration but also the structure of the lesson plan: "They didn't like it and partly was because there was so many instructions in so many parts and the admin of it all, the experiment got lost in it just the pure length of it. It was very boring; they were bored. I know the brighter students really didn't like it". T3 (who had difficulty with the method) stated: "it's the ones who have a sense of adventure [liked it], have an inquiring mind and were like, "let's go". Other ones needed a step-by-step and maybe I wasn't giving them a lot either as well so maybe it was my fault as well because I didn't get it right". T3's reflection on grappling with a new method of teaching was a good formative lesson for her. She was willing to consider that she herself could improve her ability to teach this way. T6, who taught graphing first noted that, "Some really loved it. I'm not saying all of them but it was a challenge and some of them hated it". Her pragmatic approach to solving the students' difficulty with graphing, improved many of her students' enjoyment of IBL.

Although their experiences were mixed during Topic 1, all teachers said that they would be interested in collaborating in the development of new topics. Being involved in producing new resources meant that teachers would be vested in having lesson plans that they could deliver and that their students were likely to enjoy. It would also give me an opportunity to increase their understanding of inquiry learning through regular formal and informal meetings. Lakshmanan et al. (2011) reported that teacher collaboration positively impacted teacher efficacy and practice. They go on to report evidence of benefits gained by sustained professional development over a period of time and the importance of collaborative forms of professional development. In the current study, having introduced one topic using IBL, it was important to continue with other topics to embed the methodology and enhance teacher learning through professional collaboration. Doyle (1979) in his paper on *Classroom Effects* suggests a reciprocal feedback from teacher to student and vice versa, many important teacher effects occur indirectly through the tasks teachers establish rather than directly through teacher actions in the classroom. If the teacher were to become confident using IBL, then it is likely that this would carry over to the students. Teacher self efficacy belief was tested at the end of the study where their scores were used to discover if their level of self efficacy belief could provide information on their willingness to implement IBSE in the classroom. Instructor immediacy was not studied.

At this point in the study, it was my own confidence in the importance of IBSE, imbued in me from the pre-study CoP made me feel that there had to be another way to implement IBSE successfully. Teachers needed time to accustom themselves to teaching in this manner and get a deeper understanding of the method and students had to learn to rely more on their ability to think critically.

4.4 Phase 2 Community of Practice inside school.

Four of the six teachers who participated in Phase 1 of the study were also involved in Phase 2 of the study This phase was structure in the form of a CoP. This CoP was evaluated using a Wengarian Matrix. Table 4.9 summarises the factors contributing to the formation of this CoP’s identity as a producer of inquiry learning materials. These teachers participated positively in the CoP. The experience of T5 who partially participated is also included in blue. Her role in the community was not positive. This reflects the experience of Grossman, Wineburg and Woolworth (2001) who reported the existence of tensions within working teacher communities, which may or may not be useful. T6 did not participate as she had already covered the chosen topics with her class and did not engage in the development of the new topics.

The data outlined in Table 4.7 is the synthesis of teachers' views in their two interviews and the researcher's knowledge of their involvement in other school activities. The blue text is data collected form T5 that is at variance to the other teachers' experiences within the group.

When looking at Table 4.7 teachers who did participate in the development of Topics 2 and 3 engaged well, participated in regular dialogue at all levels including curriculum development and management change. The four teachers were engaged in other communities such as resource sharing and development and cooperation in advance of subject and school evaluation. The effectiveness of this community is evidenced by the daily communication witnessed between these science teachers and their willingness to engage with all members of the science staff.

The matrix shows that the CoP was healthy as outlined by Kwan and Lopez-Real (2010). When engagement is matched with connectedness, expansiveness and effectiveness, the four teachers (and researcher) had shared experiences that involved them in other CoPs (example: taking care of Junior science laboratories) and produced the resources for the inquiry learning topics. When self image and surroundings were matched again with connectedness, expansiveness and effectiveness, there is an expectation among these teachers as part of the physical school surroundings that they regularly converse about all the CoPs to which they belong that keeps the community together. Lastly, when alignment (science department, school, Department of Education) is matched with connectedness, expansiveness and effectiveness, the community is once again shown to be healthy, all CoP members have been through changes in syllabus together that created other CoPs that in this case created good participation.

Table 4.7 Phase 2 CoP and its role in developing the use and understanding of IBSE and associated resources (Comments in blue are those of T5).

	Qualities of Identity			
		Connectedness (With others as a result of shared experiences)	**Expansiveness** (Membership of other communities)	**Effectiveness** (Participation in community)
Modes of Belonging	**Engagement** (Doing things together, talking, producing artifacts)	Engaged well with COP, good collegiality Engaged well initially, disenchanted when new pedagogy at variance with own teaching methods	Engagement in this COP improved because of other COP's Poor engagement with COP. Self reported disengagement with other COPs	Engaged well and was involved in the production of course-work Involved in the production of course-work. Only interested in own methods.
	Imagination (Self image in our surroundings)	Self image of cooperation and in regular dialogue with colleagues Self image of non-involvement and no regular dialogue with colleagues	Self image is of cooperation and sharing in other COPs Self image is of non-involvement but shares own resources	As a result of positive self image, this teacher was part of the 'glue' in the community. Due to non-involvement, did not participate in the community
	Alignment (With science department, school and Department of Education)	Been through school management changes, and syllabus changes. Good connectedness with other teachers. Been through school management changes and syllabus changes with most of other teachers: poor connectedness.	As a result of these alignments (department, school and Department of Education) many interactions with other COP's Even with these alignments (department, school and DOE), very little involvement with other COPs	Because of teacher's views of these alignments, good participation. Due to image of non- participation, not an effective group member.

As soon as it was apparent to T 5 (comments in blue, Table 4.7) that the new pedagogy was different to her own teaching methods, she no longer wished to engage with the process. She continued to misunderstand the difference between open and guided inquiry. This is discussed further in Phase 3.

The CoP developed in phase 2 was also compared with the four models outlined by McAvinia and Maguire (2011) outlined in Chapter 2.3.3. This CoP resembles Model 2: the CoP in its development built on an existing active informal network offering the opportunity to further develop existing collaboration and sharing. Firstly the participants were colleagues and were comfortable working together and secondly they already shared materials thus making the CoP effective more quickly.

4.4.1 Topic 2: Biology

Topic 2: *Structure and transport in the flowering plant* was developed with the assistance of the teachers in this CoP. The development of the topic is outlined in Chapter 3.5.2. Five teachers participated in its development and four teachers implemented the biology topic in their classes.

A decision was made at the end of the physics topic to decrease the amount of paperwork, thus no handouts were used. The teacher guided them instead of using a guided handout. They were not given worksheets or homework sheets. The teachers felt the pressure of performing well in terms of "getting the pre and post-tests right" so a decision was made to omit all paperwork.

4.4.2 Phase 2 Student survey: biology

The students' views of the biology topic by inquiry were similar statistically across the four teacher groups (using the Kruskal-Wallis analysis of variance test for 3 or more independent samples). The views of the students are important to discover if the dynamic in the class is positive to compare to teachers' views and to encourage teachers to engage. In Figure 4.3 a frequency chart is presented to indicate students' perceptions of the difficulty of the topic (n=57). Data associated with this chart are in Appendix C (viii).

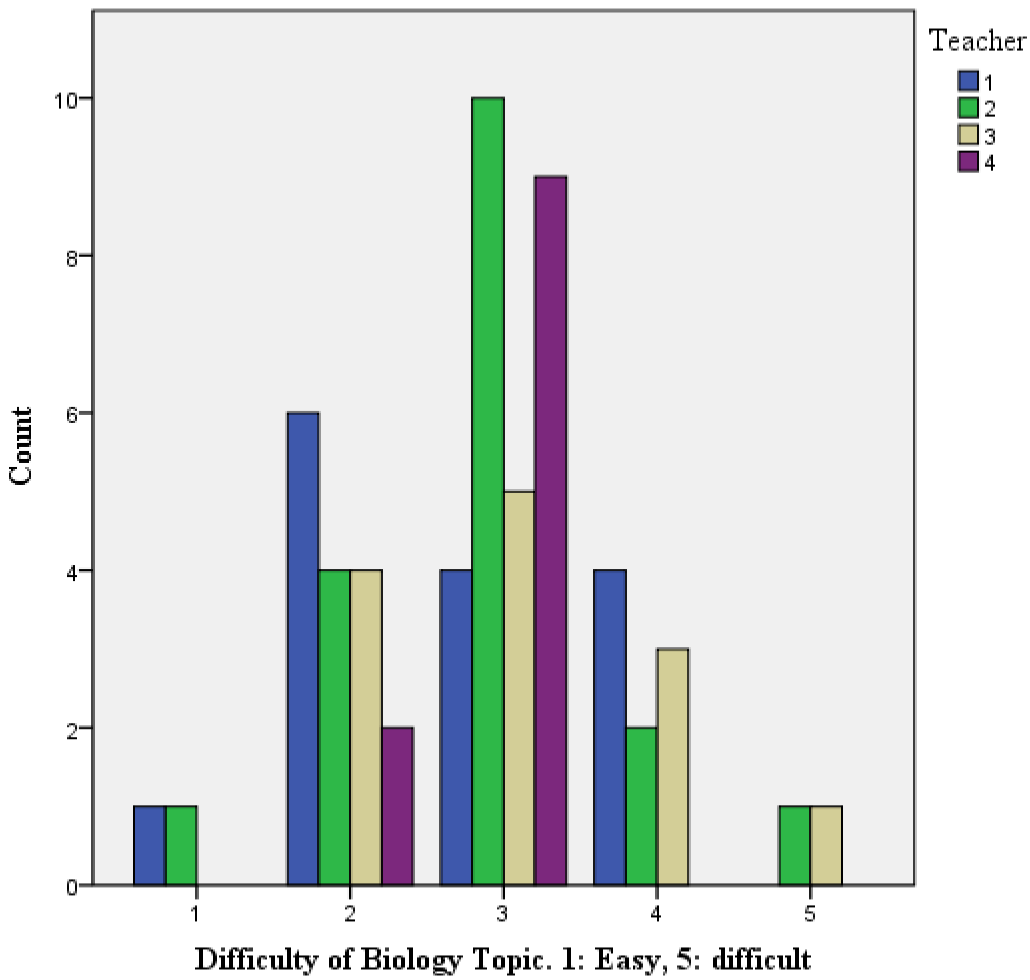


Figure 4.3 Student view of the difficulty of biology topic clustered by teacher.

The question posed to the students was: “How easy/difficult was the lesson? (1: easy, 5: difficult). The coloured bars in this chart denote the classes by teacher: T1, blue, T2, green T3, beige and T4 purple. The Y-axis is the number of students in any bar. For example only 11 of T4’s students completed the question. Two of them found it reasonably easy and nine did not find it easy or difficult.

Most students neither thought the topic was neither too difficult nor too easy. No students in T1’s class found it very difficult, skewing the data left.

Figure 4.4 outlines the students’ enjoyment of Topic 2 by teacher grouping. Data associated with this graph are in Appendix C (viii). Teachers’ perceived levels of their students’ enjoyment were greater than that reported by the students themselves. Students may have found the topic frustrating, as this was only their second encounter with IBL. Students reported that they did not find it very enjoyable nor did they dislike it. Again, the greatest counts were about the median of 3. All groups were statistically similar (using the Kruskal-Wallis analysis of variance test for 3 or more independent samples). Problems with the Hawthorne effect where subjects modify their behavior because they know they are being studied. Vescio, Ross and Adams (2008) considered that their positive findings might have resulted from teachers' interest and involvement as opposed to their involvement in a professional learning community.

The graph in Figure 4.4 was constructed in the same manner as Figure 4.3. Students' were clustered by teacher and the colour code for each teacher is displayed to the right of the graph.

In a separate question the students were asked: When you are learning something new, which do you prefer? (a) Getting taught everything. Why? (b) Figuring it out for yourself. Why? (c) A bit of both. Why?

20 of the 57 replied "a bit of both" indicating that they did have an interest in learning by inquiry while recognising that they did need guidance and scaffolding for their learning.

The students were also asked: "when you worked in groups did you: (a) Help other members in your group? (b) Get help from the group? (c) All discuss it and help each other?"

27 of the 57 students said that they would all discuss and help each other. This is also another important element of inquiry learning. At the heart of IBL is working in groups where students can collaborate and exchange ideas. This is considered an important "soft skill" in education (Hmelo-Silver, Duncan and Chinn 2007). This gives students an opportunity to discuss the problems that they have been posed and can work collaboratively. It is difficult to draw any conclusions with these data without corroborating evidence, as the response rate is low.

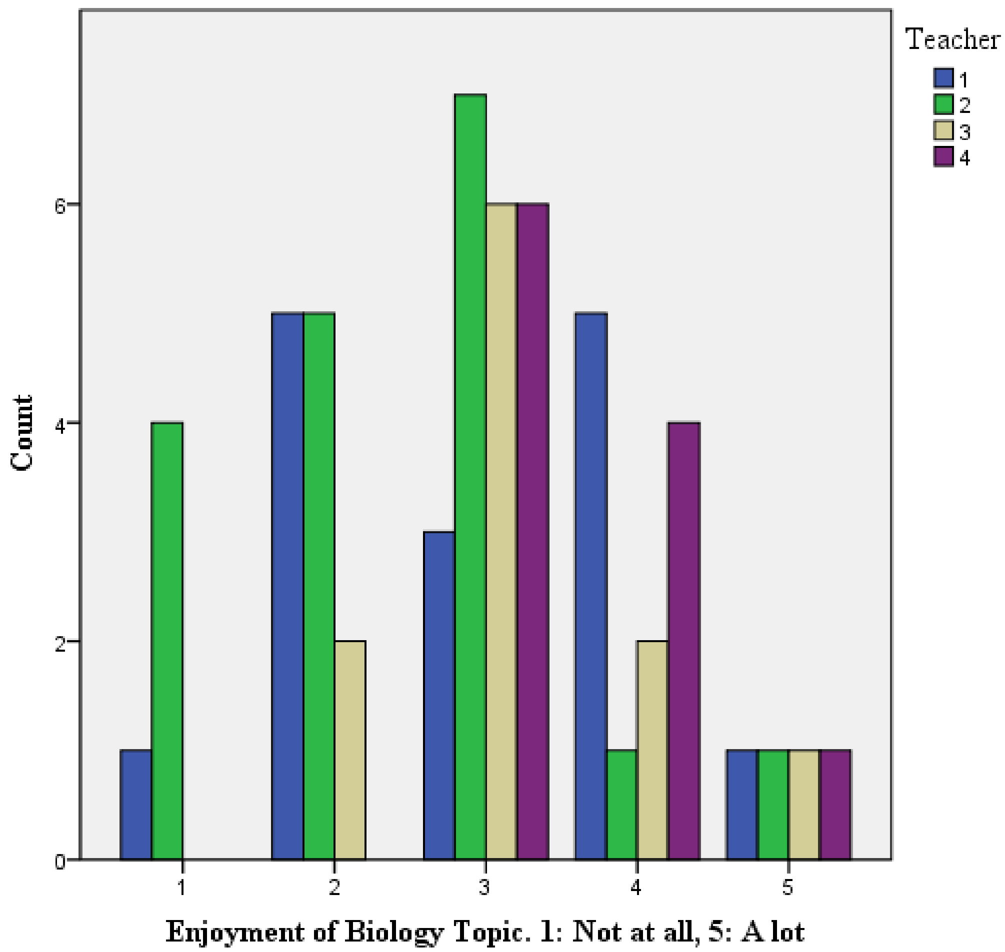


Figure 4.4 Student enjoyment of biology topic clustered by teacher.

Students' views of how their teachers teach are outlined in a word tree compiled using the statistical package NVivo 10 (Figure 4.5). The *red* circles denote the inquiry aspects and the *blue* circles denote more traditional pedagogies. This was used to provide some insight to type of teaching strategies used as identified by the student. It appears that the students noted strategies, which are associated with inquiry approaches.

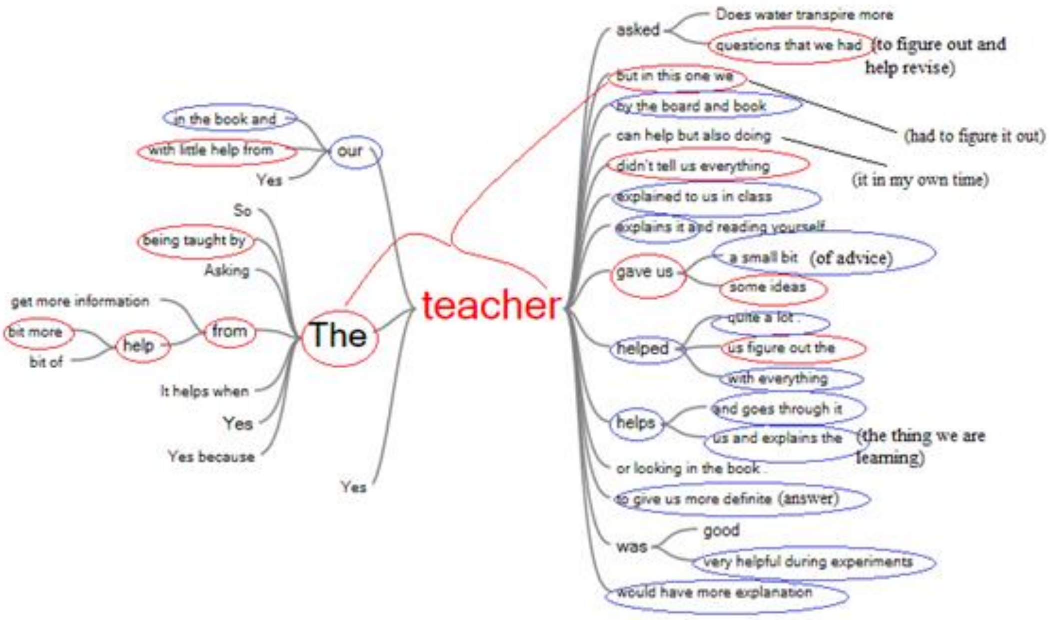


Figure 4.5 Student views of how they were taught the biology topic.

Students were required to "figure out" information for themselves. The box below provides a sample of the context for the "figure it out" phrase

"I like trying to figure out stuff and getting taught".
"She helped me figure out the answers".
"Easy to remember if you figure it out".
"There are some things you can't figure out for yourself".

Only one student wrote that there were things that could not be "figured out". This is true in some instances as scaffolding of knowledge and experience is needed before inquiry can take place. Hmelo-Silver, Duncan and Chinn (2007) argue in their paper: "that [the inquiry learning] approach involves the learner, with appropriate scaffolding, in the practices and conceptualizations of the discipline and in this way promote the construction of knowledge we recognize as learning". From the students' comments above, they appear to understand that critical thinking is important and one student also recognises the importance of scaffolding of knowledge.

In general, the students' responses confirmed that the teachers were using some inquiry in the classroom. Student and teachers' questions are important to inquiry learning (Oliviera 2010). This develops students' critical skills.

4.4.3 Phase 2 Development Survey: biology

A draft of the biology topic was prepared. This was given to DCU researchers who amended it. The next draft was given to the teachers for their comments. Involvement of teachers in the new CoP to develop materials was an effort to deepen their understanding of inquiry learning through a "hands on" approach where as they formulated the materials, they discussed and shaped their understanding of IBSE. Their comments during the development of Topic 2 are outlined in Table 4.8. This was a much richer experience for them as they could fully contribute to the topic content whereas in Topic 1 they did not have any development input. The teachers' involvement at this stage allowed them to better understand how to implement IBSE in the classroom.

T1 already used some elements of inquiry when teaching this topic. When describing how she would normally teach, she would withhold information that she felt they could figure out for themselves. When T2 described how she would have taught transport in a flowering plant no element of inquiry was evident, even to the extent that she demonstrated a very simple experiment that is easy for students to complete. When asked later in the survey if she used any inquiry learning in this unit, she felt she always did although there was no evidence of her doing so from the description of her "normal" approach. This teacher as can be seen from the first (physics) topic struggled with guided inquiry. T3 and T4 did not describe any elements of inquiry in their teaching for this topic. Marshall and Smart (2013, p.140) outline the conceptions and beliefs of their three teachers in their study. They found that although their participants were committed to the process of inquiry instruction, "the degree of each teacher's growth and proficiency relating to each of the above stages varied considerably". Similarly in this study growth and proficiency did vary, but the teachers were committed and continued with the process. Their development throughout the process is discussed in Chapter 4.5

Table 4.8 Participant teacher ideas from CoP during topic development.

Question	T 1	T 2	T 3	T 4
Typically, how would you have taught this unit	“Start with structure (have plant) and power-point then the pupils draw it. With transport, compare to humans: the tubes, xylem and phloem. Seedling in test tube with water and oil and do not explain”	“A few years since I taught it. Introducing new terms. Celery, a few plants. Do 3 experiments. Go through structure and function of each part”.	“Examined different plants including position in plant Kingdom. Looked at roots stems leaves, shape, thorns, veins: parallel or not. Seeds, test for starch Tap, fibrous roots. Buds. Read book. Draw and label parts of flowering plant. Water a wilted plant, observe. Daffodil, celery in water Experiment [in book]”.	“Bring the flowers in, dye the xylem, text book, not as much taxonomy”.
“What aspects of each class would you change, and what would you do instead?”	“Would not use plant kingdom structure. Would not use sensors [hate them] but willing to try. By class 2, would have already done seedlings in oil. TS and osmosis work is covered at L.C. So would not do it here. Would not have done stereoscopic view of roots (have none). Remember to mark the water level in seedling. Class 4: challenge too advanced”.	“Not brought in plant kingdom (too much). First class is too short. T.S and sensors too much for JC. Can speed up transpiration with hair dryer. Do slide dying as inquiry learning”.	“Sensors? Would like to learn”.	“Class 2 is too long. Did not understand class 4, need some help with it. Help with sensors, do we have enough?”

Table 4.8 Continued: Participant teacher ideas from CoP during topic development.

"What did you think about the inquiry learning aspects in each lesson?"	"Inquiry learning is brilliant but this inquiry learning in this lesson too far for [T 1's] ability. Would run away, particularly with the sensors".	"Happy to use inquiry learning".	"Very good".	"Surprised that model left until last. Class 1, not too much. Class 2 lots in this. Differentiation would be huge. Class 3 will fit in with class 1".
How many classes do you think it will take to cover this material?	"5 to 6 classes"	"The number suggested".	"4 – 5"	"Normally takes 4 periods. Class 1 fine, class 2 prep and putting away huge. Storage a problem. Could do as demo better. Class 3 will fit in with class 1".
In the past, would you have used any inquiry learning in this unit? What was it?	"Don't tell them how to do the experiment".	"Always use inquiry learning".	"Daffodil and celery dyes: Which vessel is coloured and why? Links transport (xylem) with water. Wilted leaves, (plant thirsty) water it".	"An open-ended question, not structured. Always wanted the right answer. The celery as a home experiment".
What strategies will you use alongside inquiry learning?	"Examples in the first question".	"Blank"	"Listening to their answers. Developed/ undeveloped".	"A4 sheets in groups [make them think] get ideas, hold up card. Assign different roles. Have a store of questions. If inquiry learning doesn't work, relate to everyday lesson".

When asked what parts of the topic they would change T1 felt that the expectations of what could be covered was too great and suggested the removal of two sections: osmosis and transverse section of the leaf. She rightly pointed out that these are part of the leaving certificate course. She also felt that the aspects that dealt with exchange of gasses were not important for the learning outcome.

The initial draft of Topic 2 included the use of electronic sensors to detect carbon dioxide and oxygen. Their use was no longer relevant when gas exchange was omitted. Although three of the teachers did not normally use them, they were quite happy to learn thus showing their general enthusiasm to participate.

All teachers were happy with the inquiry aspects of the topic and felt they could deliver it within the time frame suggested.

4.4.4 Phase 2 Implementation survey: biology

When teachers were surveyed on completion of Topic 2, three teachers indicated they used aspects of inquiry when teaching it. They regretted not having worksheets even though they had felt there were too many in Topic 1.They also felt that the students would need more exposure to IBL if they were to improve critical thinking.

The teachers were asked if they did anything differently to any other time that they taught transport in the flowering plant. Table 4.9 outlines their replies.

All teachers appeared happy with the topic the way it was set out subsequent to delivery. They felt that the students enjoyed the topic and were enthusiastic about it. All except T2 indicated they used some aspect of inquiry. These aspects are highlighted in blue in Table 4.9. T1 committed herself to drawing answers out of students. In T3’s classroom students were allowed to walk around and explore the resources for themselves. T4 allowed them to come up with their own ideas, This would have helped them to think critically which is an important part of inquiry learning. The teachers’ views are compared with the students’ perceptions of the topic later (Phase 3). T 1, 2 and 3 felt that students much preferred the biology topic to the physics topic. T3 responded: “The physics topic left a very bitter taste”. T4 said her students liked both. This teacher had experience of teaching by inquiry and these students were more used to the learning by inquiry.

Table 4.9 Teachers approaches to teaching Topic 2.

T 1	"We never used the textbook. I normally get the students to underline important new words etc. Tried to answer questions with questions".
T 2	"Use of more plants, use of stereoscopes".
T 3	"Plant kingdom, used stereoscopes. [Students walk around. [I] test[ed them] with various [plants]"
T 4	"Let the students come up with ideas, more practical".

Teachers felt that they would have liked worksheets. There were periods within this topic that required a waiting time of up to many days (to allow for transpiration) where they had to create other activities. This was a change from the end of the physics topic when they decided that they would prefer less paperwork.

There were mixed views whether this form of teaching would improve critical thinking. Those who felt that it would, thought that they would need more consistent teaching in this way, for critical thinking to improve. When asked how critical thinking could be tested, T3 and T4 felt that students should design their own experiments and T1 felt that appropriate questioning would be useful. One teacher felt that the current topic design was adequate. Abrami et al. (2008, p.1102) commented "as important as the development of critical thinking skills is considered to be, educators must take steps to make critical thinking objectives explicit in courses". This echoes the NRC (2000, p.25) guidelines that describe one of the essentials of inquiry: "Learners formulate explanations from evidence to address scientifically oriented questions". The teachers' comments reflect that they are beginning to understand the meaning of inquiry learning. This is important in terms of my research question: Can I change science teacher practice towards IBSE in my school? McDermott (1991) noted that earlier efforts to introduce inquiry learning into the classroom failed due to lack of teacher professional development. Providing teachers with the resources was not found to be an effective method to introduce IBSE into the classroom.

4.4.5 Topic 3: Chemistry

The Chemistry topic (Topic 3) was also developed by the school CoP. T5 did not participate in the development of this topic. The development of the chemistry topic was similar to that of the biology topic in that teachers were provided the opportunity to evaluate the materials to be included and the inquiry aspect of the topic. '*Atomic Bonding*' was chosen, as it was perceived to be difficult by the teachers and also because it was not a laboratory based activity. The reason for choosing an activity that was not laboratory based was to dispel the notion that IBL is just used in experiments.

4.4.6 Phase 2 Student survey: chemistry

This was students' third exposure to IBL. It is important to look at their perceptions of the level of difficulty of the topic particularly as the participating teachers consider this to be a difficult topic whether or not it is taught by inquiry. The questionnaire given to the students is in Appendix A (vi). Figure 4.6 shows their perceived level of difficulty of the chemistry topic. The data are colour coded by teacher. None of T1's students found chemical bonding easy. Of her 15 students 6 found the topic very difficult. This was the highest number of any group.

Students across the four groups felt differently about the difficulty of the chemistry topic. Using the Kruskal-Wallis test, T4's students found the topic the easiest compared with the other groups $p< 0.001$.

There was no significant difference in the level of student enjoyment of the chemistry topic across the four class groups (using the Kruskal-Wallis analysis of variance test for 3 or more independent samples). Figure 4.7 depicts the students' view of their level of enjoyment of the topic. The data associated with this graph are in Appendix D (viii). If it is considered that T1 felt her students were frustrated, this observation may have lead to these students enjoying the topic less. Indeed, this is borne out by the graph that shows that none of her students "really enjoyed" the topic.

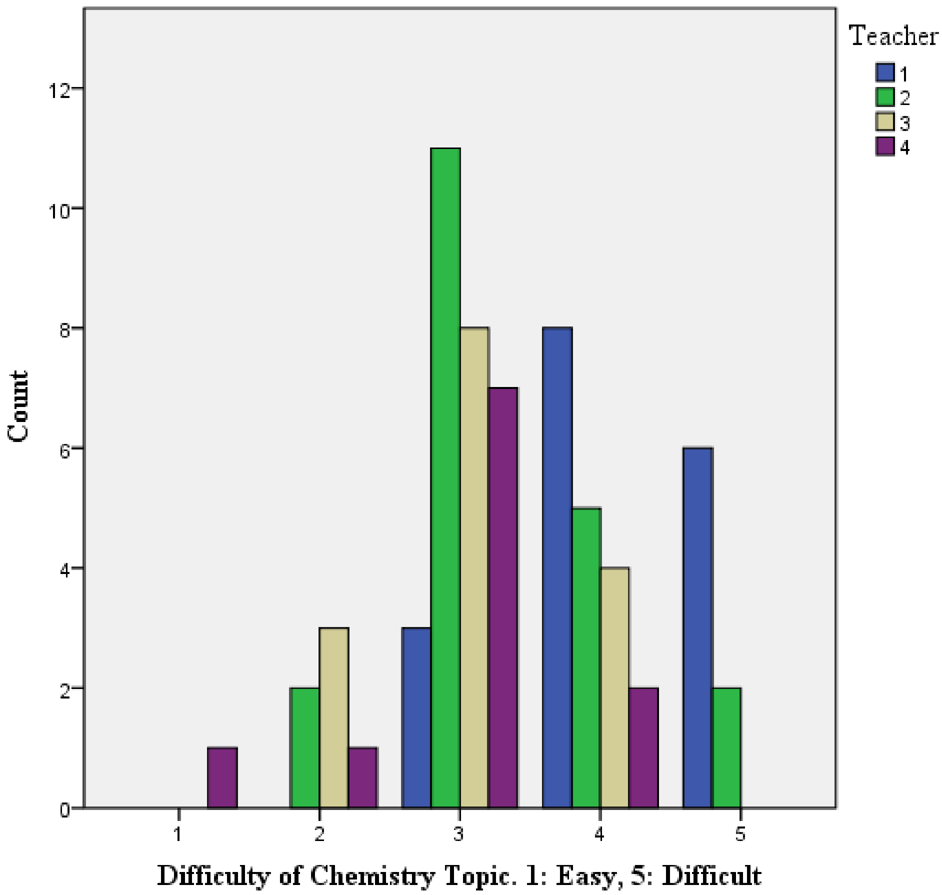


Figure 4.6 Student view of the difficulty of chemistry topic clustered by teacher.

Hargreaves (2000) in a survey of 53 teachers reported the use of emotion could be helpful or harmful raising classroom standards or lowering them. The three other teachers felt their students were somewhat happy with the topic. Chemical bonding is perceived as being a difficult which according to the participating teachers was the reason for their choice. The teachers in the first interview at the end of Phase 1 stated that students find chemical bonding difficult. They wanted to try inquiry learning when teaching the topic in the hopes that it might improve the outcome for their students. How the teachers felt their students responded (they thought they responded well) may have been an improvement over the normal response that they receive from other classes taught traditionally leading them to believe that the students were happy with the chemical bonding topic. The data associated with this graph are in Appendix D (viii).

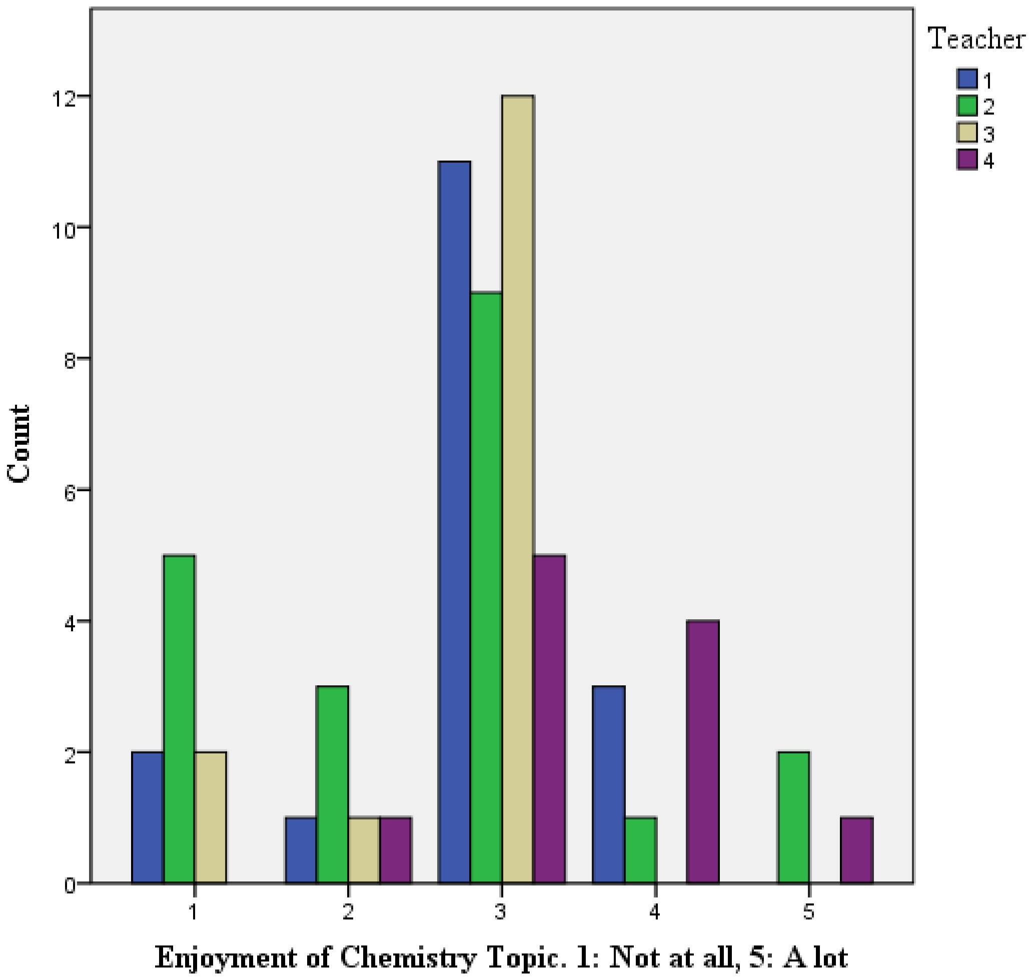


Figure 4.7 Student enjoyment of chemistry topic clustered by teacher.

T4 was the most experienced at using inquiry leaning in the classroom. This may explain why these students' impressions of the topic were more favourable in terms of difficulty. On the other hand the number of respondents in this class was lower (n=11) than other classes (T1, n=17, T2, n=20, T3, n=15), which may account for the variation in response. T1 said her students were frustrated, they reported that they did not enjoy the topic and found it difficult.

Students' responses were not as expansive as they were after the biology topic. There were fewer responses to all questions. The proportion of students who said that the teacher made them figure things out remained the same although the number of responses was lower. This may have been due to the frustrations of a difficult topic. Some students have difficulty understanding bonding.

Figure 4.8 depicts students' views of how their teachers taught this topic are outlined in a word tree compiled using the statistical package NVivo 10. Once again the level of response to all questions for Topic 3 was lower than for Topic 2. The responses were similar to the previous topic. It is reassuring the view that the teachers are still employing techniques that would be considered inquiry based learning.

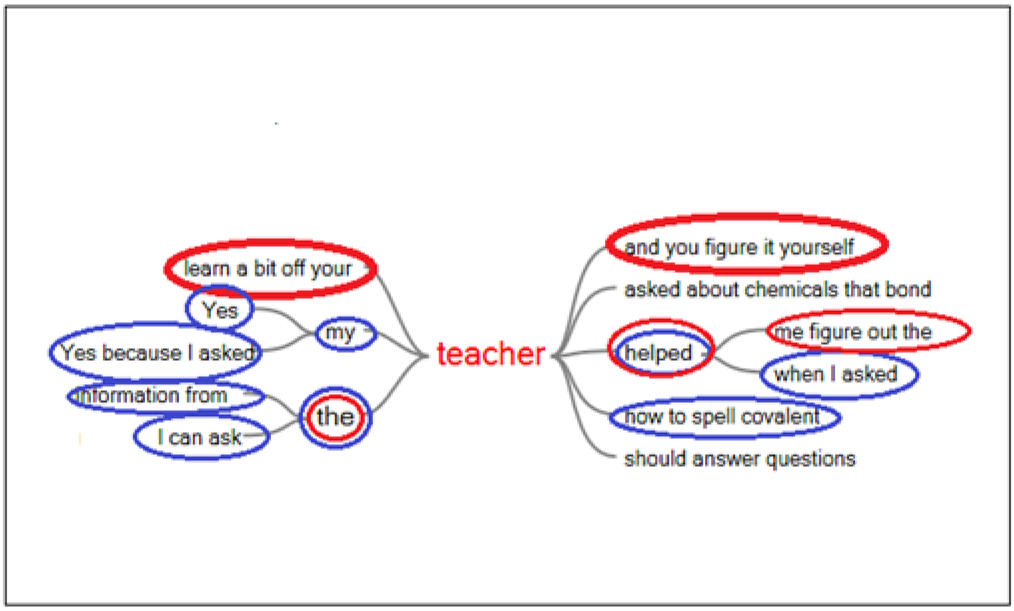


Figure 4.8 Student view of how they were taught after chemistry topic.

4.4.7 Phase2 Development survey: chemistry

A draft of the chemistry topic was prepared. This was given to DCU researchers who amended it. The next draft was given to the teachers for their comments.

All teachers would have used the white-board and some form of model, for example play dough on paper rings. Another teacher used the Junior Science Support Service resources that had an element of inquiry associated with them. They were largely happy with the organisation of the new topic that they had helped develop and were happy that worksheets were included. One teacher wished for a reorganisation of the materials to balance the timing in classes. Her wishes were incorporated into the final draft. When asked to identify aspects of inquiry within the topic, *obeying the octet rule* and *making models* were mentioned. This question was asked firstly to ascertain if the teachers could identify the aspects of inquiry and secondly to prime them before delivering the topic to insure that the students benefitted from inquiry in the topic. This was part of the strategy to deepen teachers' understanding of IBL.

When asked what length of time the topic usually took individual teachers, the variation was marked. One teacher said that it took one week but the others said up to two weeks. This divergence in practice would have caused great difficulty had the finished topic been presented to the teachers without any prior involvement. Given the teachers in the current study had control over what would be taught, how it would be taught and how long it would take to teach the topic, this increased the likelihood of their participation and also the way it was taught by them. Lakshmanan et al. (2011, p.534) in their paper observed that "changes in teachers' beliefs and changes in classroom practice mutually influenced each other and also in terms of the impact of collaboration on teacher efficacy and practice".

The teachers were asked if they had previously used inquiry for this topic. T1 said she had not. T2 who had difficulty describing guided inquiry in the previous (biology) topic answered "Asking questions about other atoms bonding after giving examples". This shows a level of development within the teacher's own understanding of inquiry learning. T3 replied that she used modeling clay but did not explain the inquiry element of using models. T4 replied, "Asking them to think and draw and see can they do it. H_2O difficult, Li_2O difficult. MgO and NaCl easy". This teacher had previous experience with inquiry learning.

Table 4.10 outlines teachers' replies to two questions before chemistry topic. The purpose of these questions was to prepare the teachers for their classroom experience. T1 did not know what else she should use alongside inquiry learning when asked how she would integrate it with her own teaching method. This loss of confidence in teaching ability was evident in the *science teacher efficacy beliefs instrument* (STEBI) scores she attained (these are discussed later). She took the implementation of the use of inquiry very seriously and had largely changed to inquiry only. T 2, 3 and 4 described methods that were largely similar to their previous methods.

Table 4.10 Teachers' replies to teaching strategy questions before chemistry topic.

	What strategies will you use alongside inquiry learning	**How would you wrap up each lesson in your own way?**
T 1	?	"Recap on work covered in class, i.e. summarise. Make sure homework is written in journals".
T 2	"Drawing ionic and covalent bonds. Tables, comparing bonds. Exp, conduction of electricity"	[Not answered]
	What strategies will you use alongside inquiry learning	**How would you wrap up each lesson in your own way?**
T 3	"Book, worksheets, posters, models, drawing out various elements".	"Summary, key points, cover all the questions in the book, workbook, worksheets, summarise, questioning, diagrams on board, you tube".
T 4	"Chalk and talk, try use you tube clips. Get them to come up with animation and applet [from you tube]"	"Go back over symbols, do you know what H is, which are stable, and do they join. Na_2O, K_2O. Some don't get the octet rule"

Teachers were asked how they would conclude the lesson to elicit what they would do and to prime them to integrate inquiry into their teaching so that they could visualise in advance how the class would unfold. Roth (1996) spoke about a "fundamental change in the professional preparation and development of science teachers" and that "questioning is a complex practice which cannot be appropriated easily". In this study the teachers recognised that they needed to teach by inquiry repeatedly to fully integrate the method into their regular class teaching.

The teachers were asked if they felt that inquiry learning would improve critical thinking. T1 replied, "Don't know. Some students find it very confusing and like to be told what they need to know and have it explained". Again the scaffolding of knowledge is important (as reported by Hmelo-Silver, Duncan and Chinn 2007 and discussed in Chapter 2). T4 replied, “Yes it would they’d have to work harder at it as they wouldn’t be spoon fed. Brickman et al. (2009) found that inquiry based learning promoted literacy and skill development although students experienced the frustrations of practicing scientists. T4’s comment appears to agree with this finding.

4.4.8 Phase 2 Implementation survey: chemistry

Teachers completed a questionnaire after the completion of the chemistry topic (Appendix A (v)). The purpose of the questionnaire was to evaluate the teachers’ experience of teaching Topic 3 by inquiry. The teachers were all positive after the chemistry topic. They did not require any changes. They also felt that the students had a positive experience, asked questions and were enthusiastic. The teachers felt that the students understood atomic bonding and the concept of “giving and sharing”. This may not be a true representation of bonding but is the model used in the current Junior Science syllabus. The students found this method easier according to their teachers. T3 commented however that the (negative) memory of the *Spring Balance* still lingered with her students and she felt that she found it difficult to motivate them to enjoy the topics.

All teachers agreed that more of this style of teaching would improve their critical thinking but T1 commented: “Students seem to get quite frustrated at times. Possibly just need to get used to this method. [I] Think they need to be told an amount of information also”. Again as outlined by Hmelo-Silver, Duncan and Chinn (2007) “IL and PBL approaches involve the learner with appropriate scaffolding in the practices and conceptualisations of the discipline and in this way promote the construction of knowledge we recognise as learning”. T1 was enthusiastic about the introduction of inquiry learning but rightly saw the need for scaffolding of knowledge associated with this. All teachers felt that the topic took longer to teach this way. They did not seem negative about this, as all of them would have said that *Atomic Bonding* is difficult to teach.

4.5 Phase 3 Teachers' recollections and self efficacy belief

After Phase 1 and 2 were completed, there was a final phase of reflection. This phase gathered all the findings from the data in Phase 1 and 2 and more data collected semi-structured in Phase 3. The data collected and analysed in Phase 3 were as follows: Phase 3 Teacher interview, and STEBI as outlined in Table 3.1. This phase drew together all the elements of Phase 1 and 2 with the results from Phase 3 to evaluate the efficacy of teacher PD for implementing IBSE.

4.5.1 Phase 3 Teacher interview

Each teacher was asked how she would define inquiry having taught the three topics. All teachers spoke about questioning the student to elicit their own knowledge, building on this foundation and prompting them to use experiments to solve problems. If these responses are compared with the "5 essentials" (outlined in Chapter 2) then it can be observed that the teachers were using some aspects of inquiry learning in their classrooms.

T1, T2 and T3 felt that the students were challenged by the approach. T3 said she felt her students were a little frightened by the approach whereas T4 who had prior experience of using inquiry learning felt the students did not really notice anything different.

The teachers' view of which kind of students enjoyed the methodology best, varied. T2 found her brighter students did not like the method, as "they wanted to be told what to do and go off and learn it off by heart". Another teacher said that it frustrated the weaker students. T3 felt that all her students enjoyed the method. If the data in Figures 4.4 (Biology) and 4.7 (Chemistry) are viewed, there are discrepancies between teachers' and students' views. In general her students did like the biology topic, but were generally less happy with chemistry than she perceived.

When asked if the students' critical thinking improved over the course of the three topics, all felt that the students did not have enough exposure to the methodology for it to make a difference.

All teachers felt that they had to prepare more before the topics. This is not surprising as the methodology was new to them. All four teachers were happy to include inquiry in their teaching. All spoke of other classes where they were now voluntarily using inquiry. All teachers remained positive although still slightly nervous about using aspects of inquiry such as using questioning to improve students' critical thinking having progressed through the three topics.

T5 participated in the first topic only even though her class groupings were suitable to continue through the whole study. She completed a final interview. When asked why she decided to opt out of the study she replied "I found the first practice utterly tedious and the students didn't like it". Students take the lead from their teachers. The teacher's negativity may have influenced the students. She said that none of her students were interested in this form of inquiry. McRobbie and Tobin (1997, p.194) reported "the principal concern [of students] being to cover the work in the most efficient way possible". When asked if the students were influenced by her attitude towards inquiry she thought not. She "just stayed away and let them at it". In this way she maintained the "teacher autonomy" within the classroom discussed by McRobbie and Tobin (1997). This teacher's statement reveals that the teacher had continued to misunderstand what was required of her to teach by inquiry. She continued to believe that all inquiry was discovery learning. When asked the type of questions that she asked her class, these were some of her responses: "give me back Hooke's law" or "put this, another way" or "tell me what I taught you". These questions would not help the students to think critically (Oliviera 2009). When talking about Coursework B (where students are required within the syllabus to perform two investigations by guided inquiry) she said she asked more open questions: "How would you do this?" This teacher felt that she had very little communication with her colleagues except on specific issues related to their own specialties. The interview suggested that she never grasped the idea that there were different forms of inquiry and that guided inquiry allowed for intervention with the student.

4.5.2 Teachers' view of inquiry learning

When asked how they normally taught, each teacher used some aspects of inquiry in the form of questioning or linking to their own experiences. They were able to build on these features to increase the level of inquiry in their teaching. In preparation for the biology topic, the teachers were given an outline of how it would be taught. As part of the questionnaire they were asked: "In the past would you have used any inquiry learning in this topic?"

All four teachers did use a substantial amount of inquiry. This was surprising as at the beginning of the study only one teacher reported understanding what was meant by inquiry learning. The teachers were pleased with the lesson planning and execution of the topic.

Chemical bonding is seen as a difficult concept (Gilbert, Justi, and Queiroz 2009) at this level. Where the biology topic is very visual, this chemistry topic is abstract. When asked before the topic if this approach would improve the students' critical thinking one teacher commented: "Some students find it very confusing and like to be told what they need to know". This is reasonably valid, as very few students would have had prior exposure to the concept of chemical bonding before. Another teacher said, "they would have to work harder as they would not be spoon-fed". When the students had finished the topic, the teachers felt that the student's response was better than before.

At the teachers' final interview, all four teachers were sufficiently happy with the pedagogy and they had started to use it in other classes, thus displaying a positive attitude towards inquiry learning.

4.5.3 STEBI Survey

Science Teacher Self Efficacy Beliefs Instrument (STEBI) is a measure of a teacher's confidence in their belief to teach science successfully in the classroom. This was measured to see if a teacher's level of self efficacy belief was related to their willingness to use IBSE in the classroom. STEBI A (Enochs and Riggs 1990) is used for in-service teachers and contains 25 questions that are answered using the Likert format: 1 strongly disagree to 5 strongly agree. The subscales PSTE, Personal science teaching efficacy and STOE, Science teacher outcome expectancy are explained in Chapter 3.4. The results of this questionnaire are shown in Table 4.11.

Table 4.11 Teachers' self efficacy beliefs.

	PSTE (% Of highest score*)	STOE (% Of highest score*)
T 1	45	47
T 2	57	48
T 3	65	49
T 4	59	44
*Lakshmanan et al. (2011)	53	42

If these values are compared with the final results of Lakshmanan et al. (2011), only T1 is below these published mean values for Personal Science Teaching Efficacy Belief. In all other cases the teachers were in the same range or above the published values. T1 had the greatest concerns of the four teachers of her student’s ability to use inquiry. According to Ross (1998), teachers with high self-efficacy show more positive affective behavior and are more likely to implement new instructional practices. All four teachers were willing to try teaching by inquiry and commented in their final interview that they had begun to use these methods with other classes at junior and senior level.

4.5.4 Progression of students’ view of inquiry

In this section, the data are aggregated and no longer clustered by teacher. The graphs (Figure 4.7 and 4.8) outline students’ views after the Topic 3 at the end of the interventions.

When asked at the beginning of the study how they liked to work, 90 of the 111 students felt that they worked well or very well with other students. After the biology topic, students were again asked how they liked to work. Most reported that they did like to work in groups. Some students reported that they like to help others. Although the number of respondents after the chemistry topic dropped, those that answered still preferred to work in groups. Working collaboratively is considered an important "soft skill" associated with inquiry learning where students can share information and help each other to solve problems.

After the biology topic students were asked how they liked to learn. Of the 54 replies, thirty percent said they would prefer to "be taught by the teacher", sixty three percent that they would like "figuring it out for themselves" and "be taught by the teacher". Only seven percent (4 students) said they would prefer open inquiry to guided inquiry. This student view indicates that they prefer guided inquiry, not discovery. At the end of the chemistry topic when the students had three formal exposures to inquiry, their views became more polarised. Twenty five percent said they would prefer to be taught and seventy five percent of students responded that that they would like a combination of figuring it out for themselves. None of the said they would only like to figure it out for them. This result is not surprising as many students found this topic difficult and they need to learn a lot of new information to have sufficient scaffolding to understand the topic.

4.5.5 Teachers' views of students' beliefs

At the end of the process teachers felt that students their students had difficulty with the first topic but their students' view subsequently improved. T4 who had previous experience of inquiry found that her students were happy with the methodology from the beginning. Much of her teaching would already have been through inquiry (Table 4.12).

According to Fogleman, McNeill and Krajcik (2011) "Students need to actively engage in inquiry investigations to develop understandings of key science concepts". All teachers in the current study felt that students would need more exposure to this method before they (the students) would be confident with it.

Table 4.12 Teachers' views of students' beliefs.

T1 Physics	“If they were asked to be taught this way again. ‘I think they’d cry” [meaning they would not be happy]
T1 Biology	“Responded well to questions asked and were enthusiastic”
T1 Chemistry	“They were quite frustrated at times. They do need to be told some information though”.
T2 Physics	“They didn't like it. So many instructions, the experiment got lost in it. ‘The brighter students didn’t like it”
T2 Biology	“Good: understanding, questions, confidence, enthusiasm”
T2 Chemistry	“Leaps of understanding. Confidence. Enthusiasm was fair but better than normal”.
T3 Physics	“Why can't we go back to the way we normally do things? The brighter ones enjoyed some aspects of the module”.
T3 Biology	“Great leaps of understanding, happy to ask questions, very good enthusiasm”.
T3 Chemistry	“Very good questioning, very good leaps of understanding, Good confidence”.
T4 Physics	‘They enjoyed, [it] the majority of them. Some of them really, really struggled and constantly asked for help”
T4 Biology	“Leaps of understanding were greater in the ‘A’ students”.
T4 Chemistry	“Very enthusiastic”.

If each teacher’s perception of their students’ views is compared, the students were not as enthusiastic or as confident as was reported by the teacher. Although the teachers felt that most students really enjoyed the biology topic, only 28% of students reported that they did. Similarly, all teachers felt their students were enthusiastic about the chemistry topic, only 29% reported that they enjoyed the topic. The percentage of students who enjoyed either topic was the same, this does not show any improvement from one topic to the next. There are many factors that contribute to the students' interest in inquiry learning.

4.5.6 Answering the research question using triangulation of data

In this section, methodological triangulation is used to test for convergence in related factors. Convergent validity is demonstrated when factors that should be related to each other are found to be so. Triangulation design examines quantitative and qualitative data of the same topic bringing together the strengths of the two methods (Punch, 2009). In this section data from interviews and surveys completed by teachers and students in the study are triangulated this to answer the research questions. Table 4.14 combines the views of teachers and students and the results of the two Likert style questions in the student surveys.

The triangulation of results from study data indicates that these teachers have incorporated IBL as a teaching strategy. Triangulation 5 results show that teacher self efficacy belief is very important in students enjoyment inquiry learning. The use of IBL in the classroom over time appears to improve teachers' comfort and students' enjoyment of the method.

In Table 4.13, there are three columns that outline the three research tools used for each triangular observation. Alongside each of these columns are the data obtained from this tool. The comment column synthesises the three relevant data sets. The final column describes the effect of the synthesis on the research questions.

RQ 1. What form of professional development is appropriate to encourage teachers to **understand** IBSE? RQ 2. What form of professional development is appropriate to encourage teachers to **use** IBSE in the classroom? RQ 3. How do implementation experiences influence teachers' **inclination to using** IBSE?

Table 4.13 Triangulation of data to answer research question.

Triangulation	Data type	Data	Data type	Data	Data type	Data	Finding
1	T1's Phase 2 development survey.	IBSE beyond her ability	T1 Phase 3 teacher interview	"They were quite frustrated at times. They do need to be told some information though".	T1 student ease/ difficulty Likert question Topic 2 and 3. Phase 2 student survey	Student values for difficulty of Topic 3 (chemistry).	CoP improved T1's understanding of IBSE and persistence with IBSE despite student issues.
2	T1's Phase 2 development survey.	I keep asking them questions to make them figure stuff out	Phase 2 student survey	"She makes us figure it out"	T1 Phase 3 teacher interview	In some ways it's easier to teach this way. I do it with my other classes now	The teacher despite lower self efficacy beliefs is committed to IBSE.
3	T2's Phase 1 teacher interview	Open to the idea of IBSE	T2 Phase 3 teacher interview	The brighter students just wanted to get on with the work. They felt IBL was time wasting.	T2 student like/ dislike Likert question Topic 2 and 3. Phase 2 student survey	Tended to dislike both topics.	Although the teacher interested in teaching using IBSE, some of her students resisted.
4	T2 Phase 2 development survey. "In the past, would you have used any inquiry learning in this unit?"	Always use inquiry.	T2's views of students' beliefs. Phase 3 teacher interview	"Leaps of understanding. Confidence. Enthusiasm was fair but better than normal".	T2 Phase 3 Interview	Use inquiry with my other classes now.	T2, despite her students' resistance, continues to implement IBSE.
5	T3 Phase 1 teacher interview.	I totally lost myself, I lost my natural self	T3 Phase 3 teacher interview	This teacher's self efficacy beliefs were the highest in the group. Her exhortation to her students was "let's have a go".	T3 student like/ dislike Likert question Topic 2 and 3 Phase 2 student survey	Tended towards liking Topic 2. They liked Topic 3 less. T3 did use questioning to elicit critical thinking.	Students were carried along by the enthusiasm and self efficacy belief of their teacher
6	T4 Phase 1 teacher interview	Is experienced at teaching by IBSE	T4 Phase 3 teacher interview	Uses IBSE all the time in her classes.	T4 student like/ dislike Likert Phase 2 student survey Topic 2, 3	Students tended towards liking both Topic 2 and 3.	Inclination to using IBSE improves with practice

Triangulation 1: (RQ 1) T1's ability to use IBSE improved during the CoP phase. This was evident from her understanding of the necessity of information scaffolding. That the students found the chemistry topic frustrating is to be expected as the teacher, using IBSE were required to think independently of the teacher to gain the knowledge and so students found the chemistry topic difficult. An alternative view is that T1's ability to use IBSE as pedagogy may have improved if the PLC had continued. The students might still have found the chemistry topic difficult if they were taught with traditional methods. It is more likely that the teacher did improve from participation in the CoP as she took an active role in developing Topic 2 and 3. As T1 is a chemistry teacher she has many strategies for teaching chemical bonding. It is likely that their difficulty was a factor of the new pedagogy, not the difficulty of the topic itself.

Triangulation 2. (RQ 1): T1 understood from the PLC that critical thinking (figuring it out for themselves) was key to IBSE. Her low self efficacy belief did not deter her from continuing with the study. The CoP gave her the opportunity to embed her use of IBSE. Her use of questioning is corroborated by the students during this phase. (RQ 3): her understanding of the necessity for critical thinking, her students' acknowledgment of the new pedagogy and her confidence in the lack of difficulty in its implementation (in spite of low self efficacy belief) increased her inclination to use IBSE

Triangulation 3. (RQ 2). Although T2's students resisted IBSE techniques, she continued to use the pedagogy. She reported that she was interested in the method. Throughout the CoP phase, some of her high achieving students continued to give negative feedback about the use of IBSE. Talking to other teachers participating in the CoP Working within the CoP, she continued to use IBSE in the class.

Triangulation 4. (RQ 3). T2 reported that she always uses IBSE for Topic 2. T2 was encouraged by students' performance citing that their understanding and confidence had improved. T2 continues to use IBSE in classes that were not participating in the study. Being exposed to IBSE in the PLC and CoP demonstrated to her that she already routinely used IBSE in some topics that she teaches.

Triangulation 5. (RQ1). T3 is a teacher with high self efficacy. She finished phase 1 unable to teach by inquiry. The CoP gave her the time to discuss its implementation with colleagues and understand how to use IBSE in the class. Her students responded well to IBSE. In her final interview she reported that she was teaching by inquiry in other classes who were not part of the study group this showing that she was inclined to use IBSE (RQ 3).

Triangulation 6. T4 is a teacher who had prior experience of teaching science by inquiry. Her students were happy to use the method and were comfortable with it. The inclination to using IBSE increases with practice. (RQ 3).

4.6 Researcher's Personal Recollections and Development.

4.6.1 Introduction

Over the course of the study, some issues arose that I felt could not be ignored if the study were to succeed in terms of the research questions: Can I change science teacher practice towards IBSE in my school? Table 4.14 outlines my recollections and the solutions I applied to the issues.

Teachers did not report the issues outlined in Table 4.14 in a formal manner. Take for instance; teachers being were unhappy to spend a full class to have students complete the WIHIC survey. Teachers did not overtly complain. Through utterances such as, "how long will it take, can we start the topic the same day, do we have to do this and the pre-test?" it became evident that they were not happy.

Bell and Gilbert (1996) proposed a model for teacher development that addressed the personal, professional and social aspects of a teacher's progress. My journey is outlined below following is the journey from inception to completion of the study.

4.6.2 Personal, professional and social development

Initial stage

The National Council for Curriculum Assessment views learning by inquiry to be important in the development of the new Junior Certificate programme. I wished to introduce myself and my colleagues to inquiry learning, in preparation for the change in curriculum. I used the physics topic developed at DCU by a CoP that comprised third level researchers in collaboration with second level teachers in which I participated.

4.14 Issues that arose during the study and my response to them.

Issue	Response
Teachers impatient about spending a full class doing WIHIC	Cut down the size of the test
Teachers had a lot of stress caused by worry about implementing inquiry and then also having a TEST at the end	Make test optional. Key to success of project is that they would understand and use IBL
Too much paperwork in first topic	Cut it down, offer paperwork as an option
Really stressed about using inquiry	Become involved in developing the next topic
A lot of students got lost in the graphing	Possibly not a good first year topic, coach them
Early on: Teachers only participating in the study to please me, not a great interest in learning or implementing the pedagogy	CoP
Embarrassment and confusion at STEBI	Continue despite the embarrassment
Teachers very brief in their answers after biology and chemistry	Another interview

Before starting this Masters in Science Education I felt it was necessary to deliver the syllabus in a more engaging way than previously. This opportunity arose from a Summer School that I attended. The programme used inquiry-based learning as a tool to improve students' interest in science. I also decided that as the Summer school used physics topics, this also would be of use to me as this was my weakest science subject. At this initial stage I was able to experience first-hand the challenges that this method posed for me as a student, which would later make me sympathetic to both fellow teachers and students.

The development of the first topic, although with a team from the university, did not include any of the staff from my own school. Using a PLC to introduce inquiry learning where a "top down" approach was used did not take into consideration the experience of other members of the group. This created an element of isolation for me from the group

Second stage

My ability to teach by inquiry improved over the three topics. I use inquiry in most classes now. I also learned to appreciate the usefulness of communities of practice for professional development. My involvement with other teachers in implementing this study was informative and enriching. I learned how other teachers taught science and the importance of individual styles.

Explaining how the topic was to be delivered to the students by other teachers in my school was very challenging on many levels. Firstly, it was important to convey to the other teachers the merits of inquiry based learning and how this topic was to be delivered to the students (allowing / prompting students to think critically and "think like scientists". Secondly, implementing inquiry in my own classroom required rewriting lesson plans to reflect this change. Lastly, changing my research methods as a scientist to a researcher in humanities presented its own problems. I felt the need to quantify every step of the process. In so doing, the teachers and students participating in the study were required to fill in so much paper work that the process of teaching and learning by inquiry was lost in the study. This set-back necessitated a re-think of how best to introduce inquiry at a whole school level.

Involving the other science teachers in my school in the development of the second and third topic proved to be more successful. This development gained the continued interest of the participating teachers. They were more confident teaching these topics by inquiry. Using CoP in this setting increased my communication with other science teachers. As the meetings were largely unstructured it was not seen as onerous or time consuming by them.

Third stage

Initially I was unsure of my standing within the community as I was not as established as many of the other teachers and so was quite reticent discussing the implementation of inquiry learning. I grew in confidence as I realised I was a valued member of the science department. I have continued to develop topics by inquiry.

The introduction of a second CoP that included the participating teachers to develop the second and third topic gave the teachers ownership of their learning. This research project has given me the confidence to embrace the new Junior Certificate curriculum when it is introduced.

CoP in this instance highlighted that this cohort of teachers had a high degree of self-efficacy (both STEBI and PSTE). Their involvement in this process of introducing inquiry learning into their teaching practice was challenging but did not discourage them. They all said they would be happy to use any other topics developed this way but now have the confidence to modify the material to suit their own needs. All have introduced learning by inquiry to their senior classes. Exposure to other teachers broadened my view of inquiry learning.

4.7 Chapter summary

The pre-study CoP at DCU was inspirational in the development and implementation of the study. Teachers were enthusiastic to participate in the PLC and all but one teacher who participated viewed it as a positive although sometimes frustrating experience. Students before the study felt they had a positive learning environment. In the first topic, responses to comprehension tests at completion were mixed. Teachers found Topic 1 difficult to implement both from an administrative and teaching perspective. Many teachers felt their students were frustrated.

In Phase 2, teachers were largely happy with the outcome. They implemented IBSE in the class and although many students found it difficult, particularly in Topic 3 the students did like working in groups.

Teachers' self efficacy was explored in Phase 3. When this information was triangulated with information gathered earlier in the study, a low level of self efficacy belief did not appear to influence the implementation of IBSE. Students who were taught by the teacher with a higher level of self efficacy belief appeared to enjoy the method more.

From my (the researcher's) perspective, I grew personally, professionally and socially.

Chapter 5. Conclusions

In this chapter key findings, outcomes, policy implications, recommendations and future research are outlined. Key findings are outlined with reference to the research questions. Outcomes are discussed in terms of the longer term effect on teacher pedagogies in my school. Reference is made to the NCCA and PDST in terms of policy implications. Recommendations and future research views the possible extention of the use of IBSE nationally.

5.1 Key findings

The findings of this case study address the research question and sub-questions outlined below. The sub-questions are in bold type-face with the associated findings underneath.
Primary research question:

Can I change science teacher practice towards IBSE in my school?

1. What form of professional development is appropriate to encourage teachers to understand IBSE?

(1) The introduction of inquiry learning using a CoP gave teachers a setting to learn to teach by inquiry and so improve their understanding of IBSE.

(2) In the CoP, teachers were required to incorporate inquiry learning into the activities they helped develop by discussing changes to draft materials and participating at a formal and informal level in the CoP. This gave teachers an understanding of IBSE and a confidence to use it.

(3) The learning experience during topic development and the introduction of key phrases such as “figure it out” as a form of instruction within the CoP increased the level of inquiry within the class.

(4) Teachers’ sustained engagement with the CoP, IBSE materials through different topics improved their understanding of IBSE.

2. What form of professional development is appropriate to encourage teachers to use IBSE in the classroom?

(5) Teachers'' involvement in a CoP appeared to encourage teachers to use IBSE.

(6) CoP promoted collegiality and support among the teachers and their ability to take the concepts developed to use them elsewhere.

3. How do implementation experiences influence teachers' inclination to use IBSE?

(7) Allowing teachers responsibility and autonomy kept them interested in implementing inquiry learning in their classrooms.

(8) All teachers reported that they had included inquiry learning into other classes including senior cycle classes thus showing that teaching a difficult topic by inquiry did encourage them from continuing to use it.

(9) Students were positive to some aspects of IBSE possibly influencing teachers to be more inclined to implement IBSE in the class.

5.2 Outcomes

Professional development of science teachers using an effective CoP may be useful as a vehicle to grow in understanding of the precepts and practices of inquiry learning. Teachers in this case continued to implement inquiry learning in other classes outside of the study with different resources and so introduced inquiry at a whole school level. CoP may be used as a model for its introduction into the classroom. Teacher self efficacy did not appear to affect implementation of inquiry learning in the classroom in this instance. Not all teachers voluntarily teach by inquiry if they perceive barriers to learning the pedagogy. Student enjoyment of inquiry learning does not necessarily reflect outcome. Learning by inquiry may be effective for many students across different ranges of ability.

5.3 Recommendations and Future research

5.3.1 Recommendations

A national strategy driven by PDST would train teacher-coordinators from each school in the education centres. These teacher-coordinators would run CoPs within their schools to promote IBSE. At the same time they would form a network nationally to develop a data base to share the materials developed in each schools CoP to encourage best practice.

5.3.2 Future research

This case study could be replicated in other schools within the second level school system. This would create a more generalisable view of the outcomes of this study.

The research question that develops from the current study is “Can I change teacher practice towards inquiry at a whole school level nationally?” CoP would be used as a model for teacher professional development in inquiry based learning. This would be implemented in a network of schools. They would agree to develop different resources for inquiry learning that could be shared across the network. The study would monitor resource development, teacher development and implementation in the classroom using tools outlined in the current study and others (discussed below). There exists already a network of senior cycle biology teachers who under the auspices of the Irish Second Level Support Service have created shared resources to teach Leaving Certificate biology. This is an example of Irish second level teachers who are interested in collaborative work to benefit all teachers. This leads me to believe that such a study would be possible. Inquiry based learning is a well recognised pedagogy to improve student critical thinking.

5.4 Policy Implications

Government policy supports IBL in Junior Certificate science (DJEI 2012). The NCCA incorporates IBL in its statements for learning (2012a) but recognises that with constraints on public funding (2012b). The Professional Development Service of Teachers (PDST) displays one course for continuing PD in IBL through CASTeL (Centre for the Advancement of Mathematics and Science Teaching and Learning) at DCU. To improve the uptake of IBL as a pedagogy, COPs both inside a school and between schools would be an effective model for PD. Teachers would be empowerd to employ IBSE as a pedagogy with a netwoork of peers at a formal and informal level through CoPs as a support system.

5.5 Summary

This study investigated some modes of professional development to improve teachers understanding, use and inclination to use IBSE in the classroom.

Being part of the CoP bolstered teachers' openness to understanding and use of IBSE despite student resistance, difficulty with implementation. CoP promoted collegiality and support among the teachers. It improved their ability to take the concepts developed to use them elsewhere. Not all teachers found the experience a success. All teachers reported that they had included inquiry learning into other classes including senior cycle classes thus showing that teaching a difficult topic by inquiry encouraged them to continue to use it.

The implication for policy makers and stakeholders is that CoP may be an effective form of PD to improve the level of IBL in the classroom. PDST could use this approach as part of its programme in Education Centres nationally.

The current research could be expanded to become a national study. A network of teachers would agree to develop different resources for inquiry learning that could be shared across a national community of practice.

Bibliography

Abrami, P.C., Bernard, R.M., Borokhovski, E., Wade, A., Surkes, M.A., Tamim, R. and Zhang, D. 2008. Instructional interventions affecting critical thinking skills and dispositions: A stage 1 meta-analysis. *Review of Educational Research*, 78(4), pp.1102-1134.

Abrandt Dahlgren, M. Castensson, R. and Dahlgren, L.O. 1998. PBL from the teachers' perspective. *Higher Education*, 36(4), pp.437-447.

Aldridge, J. M., Fraser, B. J. and Huang, T. C. I. 1999. Investigating classroom environments in Taiwan , Australia with multiple research methods. *The Journal of Educational Research*, 93(1), pp.48-62.

Alfieri, L., Brooks, P.J., Aldrich, N.J. and Tenenbaum, H.R. 2011. Does discovery-based instruction enhance learning? *Journal of Educational Psychology*, 103(1), pp.1-18.

Azar, A. 2010. In-Service and Pre-Service Secondary Science Teachers. *Educational Research and Reviews*, 5(4), pp.175-188.

Bailin, S. and Siegel, H. 2003. Critical thinking. *IN*: Blake, N., Smeyers, P., Smith, R. and Standish, P. (eds.) *The Blackwell Guide to the Philosophy of Education*, Oxford: Blackwell Publishing, 2008, pp.181-193.

Banchi, H. and Bell, R. 2008. The Many Levels of Inquiry. *Science and Children*, 46(2), pp.26-29.

Bandura, A. 1997. *Self-eflicacy: The exercise of control.* New York: W. H. Freeman.

Bandura, A. and Adams, N. E. 1977. Analysis of self-efficacy theory of behavioral change. *Cognitive Therapy and Research*, 1(4), pp.287-310.

Bell, B. and Gilbert, J. 1996. A Model for Achieving Teacher Development. *IN* Gilbert, J. (ed.) The *RoutledgeFalmer Reader in Science Education.* London: RoutledgeFalmer, pp.258-278

Bell, R. L., Smetana, L. and Binns, I. 2005. Simplifying inquiry instruction. *The Science Teacher*, 72(7), pp.30-33.

Bennett, J. 2007. *Teaching and Learning Science*. London: Continuum pp.50-72.

Blake, N., Smeyers, P., Smith, R. and Standish, P. (eds.) 2003. *The Blackwell Guide to the Philosophy of Education,* Oxford: Blackwell Publishing.

Blanchard, M. R., Southerland, S. A. and Granger, E. M. 2009. No silver bullet for inquiry: Making sense of teacher change following an inquiry- based research experience for teachers. *Science Education*, 93(2), pp.322-360

Brickman, P., Gormally, C., Armstrong, N. and Hallar, B. 2009. Effects of Inquiry-based Learning on Students' Science Literacy Skills and Confidence. *International Journal for the Scholarship of Teaching and Learning*, 3(2) pp.1-22.

Capps, D. K., Crawford, B. A. and Constas, M. A. 2012. A review of empirical literature on inquiry professional development: alignment with best practices and a critique of the findings. *Journal of Science Teacher Education*, 23(3), pp.291-318.

Chin, C. and Osborne, J. 2010. Students' questions and discursive interaction: Their impact on argumentation during collaborative group discussions in science. *Journal of Research in Science Teaching*, 47(7), pp.883-908.

Cohen, L. and Manion, L 1994. *Research Methods in Education.* London Routledge.

Cohen, L., Manion, L. and Morrison, K. 2011. *Research Methods in Education.* Abingdon: Routledge.

Creswell, J.W. 2003. *Research Design. Qualitative, Quantitative and Mixed Methods Approaches*. 2nd ed. London: Sage.

Darling-Hammond, L. and McLaughlin, M. W. 1995. Policies that support professional development in an era of reform. *Phi delta kappan*, 76(8), pp.597-604.

Darling, J. and Nordenbo, S.E. 2003. Progressivism. *IN*: Blake, N., Smeyers, P., Smith, R. and Standish, P. (eds.) *The Blackwell Guide to the Philosophy of Education*, Oxford: Blackwell Publishing, 2008, pp.288-308.

Denzin, N. K. 1997. Interpretive Ethnography. Thousand Oaks, CA: Sage. *IN* Cohen, L., Manion, L. and Morrison, K. 2011. *Research Methods in Education.* Abingdon: Routledge.

Denzin, N. K., and Lincoln, Y. S. (eds.) 2002. The qualitative inquiry reader. Thousand Oaks, CA: Sage. *IN* Cohen, L., Manion, L. and Morrison, K. 2011. *Research Methods in Education.* Abingdon: Routledge.

Department of Education and Science 1999. *Primary School Curriculum: Science* [Online]. Available from: http://www.ncca.ie/uploadedfiles/Curriculum/Science_Curr.pdf [Accessed May 2013].

Department of Education and Science 2002. *Report Of The Task Force On The Physical Sciences* [Online]. Available from: http://www.education.ie/en/Publications/Policy-Reports/Task-Force-on-the-Physical-Sciences-Report-and-Recommendation.pdf [Accessed May 2013].

Department of Education and Science 2003. *Junior Certificate Science Syllabus.* Dublin: Stationery Office [Online]. Available from: http://www.curriculumonline.ie/uploadedfiles/JC/SciencesyllabusJC.pdf [Accessed May 2013]

Department of Education (UK) 2012. *The Framework for the National Curriculum A report by the Expert Panel for the National Curriculum review* [Online]. Available from: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/175439/NCR-Expert_Panel_Report.pdf [Accessed May 2013].

Department of Jobs, Employment and Innovation 2012. *Action plan for Jobs* [Online]. Available from: http://www.djei.ie/publications/2012APJ.pdf [Accessed September 2013].

Dewey J. 1916. *Thinking in Education*. Mc Millan Company [Online]. Available from: http://www.gutenberg.org/files/852/852-h/852-h.htm [Accessed 2 May 2013].

Dorman J. P. 2003. Cross-national validation of the What Is Happening In this Class?(WIHIC) questionnaire using confirmatory factor analysis. *Learning Environments Research*, *6*(3), pp.231-245.

Doyle, W. 1979. Classroom effects. *Theory into Practice*, 18(3), pp.138-144.

Enochs, L. G. and Riggs, I. M. 1990. Further development of an elementary science teaching efficacy belief instrument: A pre-service elementary scale. *School Science and Mathematics*, 90(8), pp.694-706.

Evers, W. J. G., Brouwers, A. and Tomic, W. 2002. Burnout and Self-efficacy: A study on Teachers' beliefs when Implementing an Innovative Educational System in the Netherlands. *British Journal of Psychology*, 72, pp.227-243.

Figazzolo L. 2006 *Impact of PISA 2006 on the education policy debate* [Online]. Available from: http://download.ei-ie.org/docs/IRISDocuments/Research%20Website%20Documents/2009-00036-01-E.pdf [Accessed June 2013].

Finkelstein, N. D. and Pollock, S. J. 2005. Replicating and understanding successful innovations: Implementing tutorials in introductory physics. *Physical Review Special Topics-Physics Education Research*, 1(1), 02010-1.

Fogleman, J., McNeill, K. L. and Krajcik, J. 2011. Examining the effect of teachers' adaptations of a middle school science inquiry- oriented curriculum unit on student learning. *Journal of Research in Science Teaching*, 48(2), pp.149-169.

Garnett, P. J, Garnett, P. J. and Hackling M 1995. Students' Alternative Conceptions in Chemistry: A Review of Research and Implications for Teaching and Learning. *Studies in Science Education*, 25(1), pp.69-96.

Gash, H. and McCloughlin, T. 2010. Primary and secondary school differences in thinking about science. IN: 2nd International Congress on Educational Research in Antalya Turkey [Online]. Available from: http://staff.spd.dcu.ie/gashh/hugh4.htm [Accessed April 2013].

Gelman, R. and Brenneman, K. 2004. Science learning pathways for young children *Early Childhood Research Quarterly* 19(1), pp.150–158. Special issue on Early Learning in Math and Science.

Gibson, H. L. and Chase, C. 2002. Longitudinal impact of an inquiry- based science program on middle school students' attitudes toward science. *Science Education* , 86(5), pp.693-705.

Gilbert, J. K. 2006. On the nature of “context” in chemical education. *International Journal of Science Education*, 28(9), pp.957-976.

Gilbert, J. K., Justi, R. and Queiroz, A. S. 2009. *The Use of a Model of Modelling to Develop Visualization During the Learning of Ionic Bonding*. Presented at the European

Science Education Research Association (Isatanbul, Turkey) Strand 3: The Nature of Scientific Content.
Gillard, D. 2011. *Education in England: a brief history* [Online]. Available from: www.educationengland.org.uk/history [Accessed May 2013].

Gilleece, L., Shiel, G. and Perkins, R. 2009. *Teaching and learning international survey 2008. National report for Ireland.* Dublin: Educational Research Centre [Online]. Available from: http://www.sdpi.ie/Policy_Issues-International_Trends/talis_summary_report_for_Ireland_2009.pdf [Accessed May 2013].

Gleeson, J. 2012. The Professional Knowledge Base and Practice of Irish Post-Primary Teachers: What Is the Research Evidence Telling Us? *Irish Educational Studies*, 31(1), pp.1-17.

Golafshani, N. 2003. Understanding Reliability and Validity in Qualitative Research. *The Qualitative Report*, 8(4), pp.597-607.

Gopnik, A., Glymour, C., Sobel, D. M., Schulz, L. E., Kushnir, T. and Danks, D. 2004. A Theory of Causal Learning in Children: Causal Maps and Bayes Nets. *Psychological Review*, 111(1), pp.3-32.

Grossman, P., Wineburg, S. and Woolworth, S. 2001. Toward a theory of teacher community. *The Teachers College Record*, 103(6), pp.942-1012.

Hammond, C., Karlin, D. and Thimonier, J. 2010. Creative research science experiences for high school students. *PLoS Biology*, 8(9), pp.1-3. e1000447.

Hargreaves, A. 2000. Mixed emotions: Teachers' perceptions of their interactions with students. *Teaching and Teacher Education*, 16(8), pp.811-826.

Harris, C. J and Rooks, D. L. 2010. Managing inquiry-based science: Challenges in enacting complex science instruction in elementary and middle school classrooms. *Journal of Science Teacher Education*, 21(2), pp.227-240.

Haury, D. L. 1993. *Teaching Science through Inquiry*. ERIC/CSMEE Digest. ERIC Identifier: ED359048 Source: ERIC Clearinghouse for Science Mathematics and Environmental Education, Columbus Ohio.

Henderson, C. and Dancy, M. H. 2007. Barriers to the use of research-based instructional strategies: The influence of both individual and situational characteristics. *Physical Review Special Topics-Physics Education Research*, 3(2), pp.1-14.

Hmelo-Silver, C. E., Duncan, R. G. and Chinn, C. A. 2007. Scaffolding and achievement in problem-based and inquiry learning: A response to Kirschner, Sweller, and Clark 2006. *Educational Psychologist*, 42(2), pp.99-107.

Hodson, D. 1985. Philosophy of Science, Science and Science Education. *Studies in Science Education*, 12(1), pp.25-57.

Hord, Shirley M. 1996. *Communities of Continuous Inquiry and Improvement* [Online]. Available from: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.195.5722&rep=rep1&type=pdf [Accessed May 2013].

Johnson, R. B. and Onwuegbuzie, A. J. 2004. Mixed methods research: A research paradigm whose time has come. *Educational Researcher*, 33(7), pp.14-26.

Keys, C. W. and Bryan, L. A. 2001. Co‐constructing inquiry- based science with teachers: Essential research for lasting reform. *Journal of Research in Science Teaching*, 38(6), pp.631-645.

Kirschner, P. A., Sweller, J. and Clark, R. E. 2006. Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. *Educational Psychologist*, 41(2), pp.75-86.

Kwan, T. and Lopez-Real, F. 2010. Identity formation of teacher–mentors: An analysis of contrasting experiences using a Wengerian matrix framework. *Teaching and Teacher Education*, 26(3), pp.722-731.

Lakshmanan, A., Heath, B. P., Perlmutter, A. and Elder, M. 2011. The impact of science content and professional learning communities on science teaching efficacy and standards- based instruction. *Journal of Research in Science Teaching*, 48(5), pp.534-551.

Lave, J. and Wenger, E. 1991. *Situated learning: Legitimate peripheral participation*. Cambridge: University Press [Online]. Available from: Google Books Online [Accessed May 2013].

Lawless, G. W. and Pici, J. R. 1977. Art versus Science. *Journal of Chemical Education*, 54(5), pp.312-313.

Lee, D. H. and Shaari, I. 2012. Professional Identity or Best Practices?—An Exploration of the Synergies between Professional Learning Communities and Communities of Practices. *Creative Education*, 3(4), pp.1-4.

Levine, T. H. 2010. Tools for the Study and Design of Collaborative Teacher Learning: The Affordances of Different Conceptions of Teacher Community and Activity Theory. *Teacher Education Quarterly*, 37(1), pp.109-130.

Likert, R. 1932. A Technique for the measurement of Attitudes. New York: Columbia University Press. IN: Cohen, L., Manion, L. and Morrison, K. 2011. *Research Methods in Education.* Abingdon: Routledge pp.386-393.

Linn, M. C., Bell, P. and Davis, E. A. (eds.) 2004. *Internet Environments for Science Education.* NJ, US: Lawrence Erlbaum Associates pp.315-339.

Lotter, C., Harwood, W. S. and Bonner, J. J. 2006. Overcoming a learning bottleneck: Inquiry professional development for secondary science teachers. *Journal of Science Teacher Education*, 17(3), pp.185-216.

Loucks-Horsley, S., Hewson, P., Love, N. and Stiles, K. 1998. *Designing professional development for teachers of mathematics and science.* Thousand Oaks, CA: Corwin Press.

Lynch, S., Kuipers, J., Pyke, C. and Szesze, M. 2005. Examining the effects of a highly rated science curriculum unit on diverse students: Results from a planning grant. *Journal of Research in Science Teaching,* 42(8), pp.912-946.

McAvinia, C. and Maguire, T. 2011. Evaluating the National Digital Learning Repository (NDLR): New Models of Communities of Practice. *All Ireland Journal of Teaching and Learning in Higher Education*. 3(1), pp.391-19.

McDermott, L. C. 1991. Millikan Lecture 1990. What we teach and what is learned-Closing the gap. *American Journal of Physics*, 59(4), pp.301-315.

McDermott, L. C., Rosenquist, M. L. and Van Zee, E. H. 1987. Student difficulties in connecting graphs and physics: Examples from kinematics. *American Journal of Physics*, 55(6), pp.503-513.

McRobbie, C. and Tobin, K. 1997. A social Constructivist Perstective on Learning Environments. International Journal of Science Education, 19(2), pp.193-208.

Marshall, J. C. and Smart, J. B. 2013. Teachers' Transformation to Inquiry-Based Instructional Practice. *Creative Education*, 4(2), pp.132-142.

Matthews, P. 2007. The relevance of science education in Ireland. [Online]. Available from: http://www.ncca.ie/uploadedfiles/Primary/Science_Phase2_Final_report.pdf [Accessed May 2013].

Minichiello, V. Aroni, R. Timewell, E. and Alexander, L. 1990. *In-depth interviewing: Researching people*. Longman Cheshire. In: Punch, K. F. 2009. *Introduction to Research Methods in Education*. London: Sage.

Minner, D. D., Levy, A. J. and Century, J. 2010. Inquiry- based science instruction—what is it and does it matter? Results from a research synthesis years 1984 to 2002. *Journal of Research in Science Teaching*, 47(4), pp.474-496.

National Council for Curriculum Assessment 2011. *Towards a Framework for Junior Cycle Innovation and Identity* [Online]. Available from: http://ncca.ie/framework/doc/NCCA-Junior-Cycle.pdf [Accessed May 2013].

National Council for Curriculum Assessment 2012a. *Framework for Junior Cycle Junior Cycle* [Online]. Available from: http://www.juniorcycle.ie/NCCA_JuniorCycle/media/NCCA/Documents/JC-Framework_FINAL_02oct12.pdf [Accessed September 2013].

National Council for Curriculum Assessment 2012b. *Strategic Plan 2012-2015* [Online]. Available from: http://www.ncca.ie/en/file/ncca/NCCA-Strategic-Plan-2012-2015.pdf [Accessed September 2013].

National Council for Curriculum Assessment 2013. Senior Key Skills Framework [Online]. Available from: http://www.ncca.ie/en/Curriculum_and_Assessment/Post-Primary_Education/Senior_Cycle/Key_Skills_Framework/KS_Framework.pdf [Accessed May 2013].

National Research Council 2000. “*Inquiry and the National Science Education Standards: A Guide to Teaching and Learning*” [Online]. Available from: http://www.nap.edu/catalog/9596.html [Accessed May 2013].

National Science Education Standards National Committee on Science Education Standards and Assessment, National Research Council 1996 [Online]. Available from: http://www.nap.edu/catalog/4962.html [Accessed May 2013].

Nuffield Foundation 2012. “I do and I understand” Half a Century of Curriculum Development [Online]. Available from: http://www.nuffieldfoundation.org/sites/default/files/files/Half_a_century_of_curriculum_dev_v_FINAL_WEB.pdf [Accessed May 2013].

Onwuegbuzie, A. J. and Johnson, R. B. 2006. The validity issue in mixed research. *Research in the Schools*, 13(1), pp.48-63.

Oliveira, A. W. 2010. Improving teacher questioning in science inquiry discussions through professional development. *Journal of Research in Science Teaching*, 47(4), pp.422-453.

Osborne, J. and Dillon J. 2008. *A Report to the Nuffield Foundation. King's College, London.* [Online]. Available from: http://www.nuffieldfoundation.org/sites/default/files/Sci_Ed_in_Europe_Report_Final.pdf [Accessed May 2013].

Palincsar, A. S., Magnusson, S. J., Marano, N., Ford, D. and Brown, N. 1998. Designing a community of practice: Principles and practices of the GIsML community. *Teaching and Teacher Education*, 14(1), pp.5-19.

PRIMAS guide for professional Development Providers 2010 [Online]. Available from: http://www.primas-project.eu/servlet/supportBinaryFiles?referenceId=2&supportId=1300 [Accessed May 2013].

Prince, M. and Felder, R. 2007. The many faces of inductive teaching and learning. *Journal of College Science Teaching*, 36(5), pp.14-20.

Punch, K. F. 2009. *Introduction to Research Methods in Education*. London: Sage.

Rennie, L. J., Venville, G. and Wallace, J. 2011. Learning science in an integrated classroom: Finding balance through theoretical triangulation. *Journal of Curriculum Studies*, 43(2), pp.139-162.

Riggs, I. M. and Enochs, L. G. 1990. Toward the development of an elementary teacher's science teaching efficacy belief instrument. *Science Education*, 74(6), pp.625-637.

Rocard, M. O. 2007. *Science Education Now: A Renewed Pedagogy for the Future of Europe. European Commission. Community Research* [Online]. Available from: http://ec.europa.eu/research/science-society/document_library/pdf_06/report-rocard-on-science-education_en.pdf [Accessed May 2013].

Rogoff, B. 1994. Developing understanding of the idea of communities of learners. *Mind, Culture, and Activity*, 1(4), pp.209-229.

Ross, J. A. 1998. The antecedents and consequences of teacher efficacy. In J. Brophy (ed.), *Advances in research on teaching* Greenwich, CT: JAI Press, vol. 7, pp.49–73.

Roth, W. M. 1996. Teacher questioning in an open- inquiry learning environment: Interactions of context, content, and student responses. *Journal of Research in Science Teaching*, *33*(7), pp.709-736.

Scott, P. 2004. Teacher talk and Meaning Making in Science Classrooms.IN: Gilbert, J. (ed) *The RoutledgeFalmer Reader in Science Education*. London: RoutledgeFalmer, pp.74-96.

Siegel, H. 2003. Educating reason: Rationality, critical thinking, and education. *IN*: Blake, N., Smeyers, P., Smith, R. and Standish, P. (eds.) *The Blackwell Guide to the Philosophy of Education*, Oxford: Blackwell Publishing, 2008, p.288

Taylor, J.H. and Bilbrey, J.K. 2011. Teacher Perception of Inquiry Based Instruction vs. Teacher-Based Instruction. *International Review of Social Sciences and Humanities,* 2(1), pp.152-162.

TIMSS 2011 [Online]. Available from: http://timss.bc.edu/TIMSS2011/index.html [Accessed Sept 2013].

Tobin, K. and McRobbie, C. J. 1997. Beliefs about the nature of science and the enacted science curriculum. *Science and Education*, 6(4), pp.355-371.

van Uden, J. M., Ritzen, H. and Pieters, J. M. 2013. I think I can engage my students. Teachers' perceptions of student engagement and their beliefs about being a teacher. *Teaching and Teacher Education*, 32, pp.43-54.

Vescio, V., Ross, D. and Adams, A. 2008. A review of research on the impact of professional learning communities on teaching practice and student learning. *Teaching and Teacher Education*, 24(1), pp.80-91.

Wenger, E. 1998. Communities of practice: Learning as a social system. *Systems Thinker*, 9(5), pp.2-3.

Wenger, E. 2002. Communities of practice and social learning systems. *IN:* Nicolini, D, Gherardi, S and Yanow D. (eds.) *Knowing in organizations: A practice based approach.* New York: M.E. Sharpe, pp.76–99.

Wenning, C. J. 2010. Levels of inquiry: Using inquiry spectrum learning sequences to teach science. *Journal of Physics Teacher Education Online*, *5*(4), pp.11-19.

Wenning, C. J. 2012. (updated online 2010). Levels of inquiry: Using inquiry spectrum learning sequences to teach science. *Journal of Physics Teacher Education Online*, *5*(4), pp.11-19.

Wood, K. 2011. *Education the Basics.* Oxon: Routledge.

Wilson, C. D., Taylor, J. A., Kowalski, S. M. and Carlson, J. 2010. The relative effects and equity of inquiry- based and commonplace science teaching on students' knowledge, reasoning, and argumentation. *Journal of Research in Science Teaching*, 47(3), pp.276-301.

Young, M. 2008. From constructivism to realism in the sociology of the curriculum. *Review of Research in Education*, 32(1), pp.1-28.

Appendices

Table of Contents

Appendix A Questionnaires, surveys and interviews

Appendix A (i) Adapted WIHIC Survey.

Circle the answer that you think is true for you	[1] almost never, [2] seldom, [3] sometimes, [4] often, and [5] almost always.				
I work well with other class members ……	[1]	[2]	[3]	[4]	[5]
I help other class members who are having trouble with their work.	[1]	[2]	[3]	[4]	[5]
The teacher moves about the class to talk with me.	[1]	[2]	[3]	[4]	[5]
The teacher's questions help me to understand.	[1]	[2]	[3]	[4]	[5]
I give my opinions during class discussions.	[1]	[2]	[3]	[4]	[5]
I ask the teacher questions.	[1]	[2]	[3]	[4]	[5]
I am asked to think about the evidence for statements.	[1]	[2]	[3]	[4]	[5]
I carry out investigations to answer questions that puzzle me.	[1]	[2]	[3]	[4]	[5]
I know the goals for this class.	[1]	[2]	[3]	[4]	[5]
I pay attention during this class.	[1]	[2]	[3]	[4]	[5]
I try to understand the work in this class.	[1]	[2]	[3]	[4]	[5]
When I work in groups in this class, there is teamwork.	[1]	[2]	[3]	[4]	[5]
I learn from other students in this class.	[1]	[2]	[3]	[4]	[5]
I receive the same encouragement from the teacher as other students do.	[1]	[2]	[3]	[4]	[5]
I get the same opportunity to answer questions as other students.	[1]	[2]	[3]	[4]	[5]

Appendix A (ii) Phase 1 pre- and post- test questions and coding.

Pre1. In the diagram there is a picture of a spring. Measure its length and write the answer underneath it.						
	Spring	Spring + hook	Entire Wire	Nothing	Other	
Code	1	1	1	8	2	8
Post 1. Using the experiment you have just finished, how would you find the mass of a set of keys?						
	Used spring balance	Weigh on balance	Other			
Code	1	2	2			
Pre 2. What would happen if you put a mass on the spring shown in the diagram?						
	Longer	Longer, gravity	Longer, Weight	Incorrect	Other	Blank
Code	1	1	1	2	2	8
Post 2. When measuring the extended length of a spring, does it matter if it is measured from the top of the spring						
	No + good reason	No + poor reason	Yes	Yes, likely misunderstood question	Other	
	1	1	2	2	2	
Pre 3. What would be the difference if you set this up on the moon?						
	Allude to gravity	Less weight	Float/ no gravity	Other		
Code	1	1	2	2		
Post 3. If the gravity on the moon is 1/6 of that on Earth, what would the weight of a 60g object be on the moon?						
	0.1N	10 g	Incorrect	Other		
Code	1	1	2	2		
Pre 4. What is the difference between mass and weight						
	Force	Gravity	D=MXV	Other	Units only	
	1	1	3	3	3	
Post 4. Where on the graph would you place a mass of 10g on the graph above?						
	At 0.1 N on scale	Mixed up N and g	Description no numbers	100 N	Other	
Code	1	1	1	2	2	
Pre 5. What is the force called that drags the spring downwards?						
	Gravity	Weight/ Force	Mass			
Code	1	2	2			
Post 5. Explain why do you think the graph above levels off?						
	Beyond elastic limit	Gravity levels off	No weight added on	Spring does not go any further	Don't know	Other
Code	1	2	2	1	2	2

Appendix A (iii) Phase 1 Teacher Interview.

1	Were you open to the idea before hand?
2	Did you feel you got enough guidance before the study started?
3	What were your impressions before you started (workable or not?)
4	What did the students think?
5	What would you change?
6	What sort of lead- in did you have before you started the lab?
7	On a scale of 1- 5 was it more or less organised for you than a regular lab?
8	On a scale of 1- 5 was it more or less organised for the pupils than a regular lab?
9	How do you feel about the method now?
10	Did you use any other method of teaching while covering this topic?
11	Did you change your own teaching methods with this Hooke's Law module?
12	How would you describe you own teaching method?
13	Was there a group of students in your class who enjoyed some aspect of the process and what was that?
14	What you understand by the term "Inquiry Based Science Teaching"
15	Would you be comfortable integrating some aspects of IBL *ALONGSIDE* your own teaching methods, particularly with less paperwork?
16	What aspects of the science curriculum would you like to teach with an IBL aspect to it?
17	Would you like to contribute comments during the development of the unit?
18	The only paperwork associated with it would be a pre and post-test. Would this be acceptable?

Appendix A (iv) Phase 2 Development Survey.

Question	**Question type**	**Reason for question**
Typically, how would you have taught this unit?	Open	Recollection and visualisation
What aspects of each class would you change, and what would you do instead?	Open, guided	Teacher view of topic
Can you identify at least one IBL aspect in each lesson?	Specific	Teacher view of IBL
How many classes do you think it will take to cover this material?	Specific	Teacher view of topic
In the past, would you have used any inquiry learning in this unit? What was it?	Guided, specific	Teacher view of IBL
What strategies will you use alongside IBL?	Guided	Recollection and visualisation
How would you wrap up each lesson in your own way?	Open	Recollection and visualisation
Would an increased use of this approach affect students' critical thinking? If so how?	Open, guided	Reflection
How would you measure the difference between the two teaching methods?	Specific	Teacher view of IBL

Appendix A (v) Phase 2 Implementation Survey.

Question	Question type	Rationale for question
What did you do differently when you used this unit?	Open	Recollection and visualisation
Are there any parts of the unit that you would now change?	Specific	Teacher view of IBL
How did the students respond to it? a. Understanding b. Questions asked c. Leaps of understanding, d. Confidence e. Enthusiasm	Specific, measurable	Teacher view of student view
When you were looking at the results of the post-test (Transpiration/ Covalent vs ionic bonds) did you get the students to deduce what happened	Specific	Teacher view of students work. [very poor uptake of post-test]
Did they grasp (the necessity for a control?/ the difference between 'sharing' and 'giving'?)	Specific	Teacher view of student view
How would you compare their response to this module with their response to the spring balance module?	Open	Teacher view of student view
Would you have liked worksheets and homework questions? (Topic 2)	Specific	Teacher view of topic
Do you think that more of this style of teaching would improve their critical thinking?	Open/	Reflection
How else do you think critical thinking could be tested?	Open	Reflection
How does the time taken to teach this unit compare with how you would normally have taught it?	Guided	Reflection

Appendix A (vi) Phase 2 Student Survey.

Question	Question type	Reason for question
Did you enjoy the plant structure unit? (1) (2) (3) (4) (5)	Specific, Likert, Ordinal data	Opinion
What parts did you like best?	Open	Reflective
What new words did you have to learn?/Did you have many new words to learn?	Specific	Recall
How easy/ difficult was the lesson? (1: easy, 5: difficult) (1) (2) (3) (4) (5)	Specific, Likert, Ordinal data	Opinion
During this session if you asked the teacher a question, did the teacher explain the answer or did s/he help you to figure it out yourself? Give an example.	Guided/ specific	Reflective/ recall
(a) What sort of questions did the teacher ask the class? Give examples (b) Did the questions mentioned help you remember what you learned?	Guided/ specific	Reflective/ recall
(a) Did you ask your teacher questions? Give an example. (b) How did the teacher answer the questions mentioned above? Did s/he answer the questions directly or did s/he prompt you to answer the questions yourself?	Guided/ specific	Reflective/ recall
When you are learning something new, which do you prefer? (a) Getting taught everything. Why? (b) Figuring it out for yourself. Why? (c) A bit of both. Why?	Specific	Opinion
When you worked in groups did you (a) Help other members in your group? (b) Get help from the group? (c) All discuss it and help each other?	Specific	Opinion
If you were to learn this again, is there anything you would like to see changed?	Open	Reflective

Appendix A (vii) Phase 3 Interview.

1	Was there a group of students in the class who enjoyed some aspect of the process of IBL and what type of student were they and what did they enjoy?
2	Do you think you have integrated some aspects or IBL into your teaching alongside your own teaching methods?
3	Which of the following interested the students during the project phase, was it the inquiry, was it the practical work, or was it working with other students or was it a combination of all of them?
4	were the students influenced by your attitude to the units?
5	outside of inquiry, of the three units, Hooke's Law, Transpiration or Bonding can you rank them in order of your most to your least favourite topic?
6	How would you now describe IBL after gone through the process in the last two years?
7	What aspect of your teaching do you think is inquiry teaching?
8	Would you incorporate it in your teaching?
9	student active listening is an important part of IBL. What do you think acting thinking is?
10	what did the students think of the process? Was it a change from normal for instance?
11	Did they like the freedom it gave them?
12	what did they think of the necessity to think for themselves?
13	Questions are an important part of IBL. Can you give me examples of questions you ask and rank from most to least, 5 to 1 in terms of IBL content?
14	Did you feel challenged by it?
15	how do you feel the students' attitude to guided inquiry changed over time? Did they notice?
16	Do you feel that these modules have served to improve towards the students' critical thinking?
17	Do you interact with other Science teachers as a result of the shared experience of IBL?
18	What sort of professional interaction would you normally have with your colleagues?

Appendix A (viii) Phase 3 STEBI Survey.

1	When a student does better than usual in science, it is often the teacher exerted a little extra effort.
2.	I am continually finding better ways to teach science.
3.	Even when I try very hard, I don't teach science as well as I do most subjects.
4.	When the science grades of students improve, it is most often due to their teacher having found a more effective teaching approach.
5.	I know the steps necessary to teach science concepts effectively.
6.	I am not very effective in monitoring science experiments.
7	If students are underachieving in science, it is most likely due to ineffective science teaching
8.	I generally teach science ineffectively.
9.	The inadequacy of a student's science background can be. overcome by good teaching.
10.	The low science achievement of some students cannot generally be blamed on their teachers.
11.	When a low achieving child progresses in science, it is usually due to extra attention given by the teacher
12.	I understand science concepts well enough to be effective in in teaching elementary science.
13	.Increased effort in science teaching produces little change students' science achievement. some
14.	The teacher is generally responsible for the achievement of students in science.
15.	Students' achievement in science is directly related to their teacher's effectiveness in science teaching.
16.	If parents comment that their child is showing more interest in science at school, it is probably due to the performance of the child's teacher.
17.	I find it difficult to explain to students why science experiments work.
18.	I am typically able to answer students' science questions.
19.	I wonder if I have the necessary skills to teach science.
20.	Effectiveness in science teaching has little influence on the achievement of students with low motivation.
21.	Given a choice, I would not invite the principal to evaluate my science teaching.
22.	When a student has difficulty understanding a science concept, I am usually at a loss as to how to help the student understand it better.
23.	When teaching science, 1 usually welcome student questions.
24.	I don't know what to do to turn students on to science.
25.	Even teachers with good science teaching abilities cannot help some kids learn science.

Appendix B: Topic 1: Physics

Appendix B (i) Pre-test and rationale associated with each question.

	Question	Rationale
Pre. 1	In the diagram there is a picture of a spring. Measure its length and write the answer underneath it.	This question required the student to physically measure the length of a spring that is pinted on the page. This gave them the freedom to measure the coiled part of the spring or from the hook to the loop or any combination of this. The students had to form this question and then decide which (in their view), was the valid measurement. From an inquiry point of view, this (minimal) freedom allows them to discuss to considerable depth why this is so
Pre. 2	What would happen if you put a mass on the spring shown in the diagram? Give your answer either by changing the drawing or write as a sentence.	The expectation was that all students would be able to answer this question as they could draw from everyday examples as a guide.
Pre. 3	What would be the difference if you set this up on the moon?	This was also a priming question. We hope it would lead the students to firstly recognize that weight is a force applied to a mass and secondly that that force may not always be the same for the same mass.
Pre. 4	What is the difference between mass and weight?	The students were only able to answer this question if they had prior knowledge. This allowed the teacher to assess if the student had enough information to fully understand the lesson of opposing forces. that connects with another part of the curriculum
Pre. 5	What is the force called that pulls the spring downwards?	This was a priming question to start the student thinking about opposing forces.

Appendix B (i) (Continued): Rationale associated with experiment questions.

	Question	Teacher notes: what the question was designed to do.
Exp 1	Pick up the spring, and hang different masses on it. What do you notice?	Gives the students the opportunity to explore how to use the equipment. Most will understand in a qualitative way that the more weight that is applied the longer the spring will become. The idea of proportionality is not necessary at this stage
Exp 2	Draw the spring below in two different situations: (a) when no mass is hanging on it, and (b) when there is a mass hanging on it.	This begins to introduce opposing forces and proportionality. This question prepares the students for Questions in the next three questions.
Exp 3	The diagram shows a spring before and after a mass hanger is attached. Use a ruler to measure, **on the diagram** at right: The length of the unextended spring, (a): The length of the extended spring, (b): Now calculate the extension of the spring.	First students practice what they need to measure in the lab (Q5) on paper. The extension is found by subtracting the two lengths. Students are free to measure the length of the spring any way they like, as long as they do so consistently. This question relates back to the pre-test and so they get an opportunity to discuss which is 'right way' to measure. The language here proved difficult for the weaker students: 'Extended length, extension and un-extended length before / after weight was applied' were simplified to 'distance between ……before and after the weight was added'.

Appendix B (i) (continued). Rationale associated with experiment questions.

	Question (continued)	Rationale (continued)
Exp 4	Compare your answers in Question 3 with those from another group. Did you get the same value for the extension of the spring? Did you get the same values for the lengths of the spring? Explain how you might have different values for the length of the spring, but still get the same value for the extension.	Lets students think about why you may choose different lengths, but still get the same extension.
Exp 5	Hang the spring on the retort clamp, and measure the length before and after you put the mass hanger on. The length of the un-extended spring: The length of the extended spring: Now calculate the extension of the spring:	The students use the skill of measurement (Q3) and the experience of setting up the apparatus (Q1). This gives them the freedom to experiment with different weights.
Exp 6	When the mass hanger is hanging still on the spring, which forces are pulling or pushing on it? What happens to the spring when you put one of the disks on the mass hanger? Explain this statement: "When the spring gets longer, it pulls harder".	The essence of understanding opposing forces. Although this is not essential for understanding Hooke's Law at the level of Junior Science in secondary school, it does serve to improve critical thinking an important part of inquiry learning. It also avoids fragmentation of knowledge. All the pieces are in the JC textbooks, but the links are not made.

Appendix B (i) (continued) Rationale associated with experiment questions.

	Question (continued)	Rationale (continued)
Exp 7	Look at the set-up shown in the diagram. How could you use it to measure how the extension of the spring changes when it applies different forces?	This is an opportunity for students to plan the experiment beforehand rather than to analyse it after, as this resembles more authentic inquiry.
Exp 8	Set up the experiment, and make measurements that allow you to complete Table 1. You should make a measurement for each mass you add to the spring. If you are not sure of the mass of the hanger or the disks, ask your teacher. Remember that for every 100 g there is a force of about 1 N due to the pull of the Earth.	It was decided that the students should be provided with a blank table with headings to guide them with the experiment. This would be more age appropriate and in line with guided inquiry instead of open inquiry. They were also guided to record the weight of the hanger and its associated extension. In general students use a pre-printed experiment book that is just filled in.
Exp 9	Plot a graph for the extension (not the length) of the spring against the force applied. Plot the force on the horizontal axis, the length on the vertical axis.	This proved to be the most challenging question in the activity. In subsequent iterations the number of graphs was decreased. The version given to teachers for the purpose of the study incorporated two graphs to be completed in school and two for homework. This was decreased to two (one in school and one at home) after the study.

Appendix B (i) (continued) Rationale associated with experiment questions.

	Question (continued)	Rationale (continued)
Exp 10	Q10 Remove the mass hanger, and hang an object such as a set of keys or a heavy pen on the spring. Measure the length and extension of the spring and then fill in your results in Table 2. Use your graph on the previous page to determine the force the spring exerts on the object you hung on it. Determine the mass of the object. Show your work.	Addresses the learning outcome in the syllabus where the student is required to obtain the mass of an unknown object using a spring balance. Once again the student was given a table to guide them. By completing this table they accumulated the relevant information to find the mass of the object. They were free to use any object they wished to measure. This freedom meant they had to decide what would be appropriate: could the object hang from the balance, was it too light/ heavy? All of these questions would foster their ability to inquire.
Exp 11	Measure the mass of the same object with a mass balance. How does the value compare to yours?	Helps the student validate what they have already completed. It also demonstrates to the student that verification of results is an important part of inquiry.
Exp 12	On the next page, plot a graph for the length (not the extension) of the spring against the force applied. Plot the force on the horizontal axis, the length on the vertical axis. Do not yet draw a best fit line. What is the length of the spring when no mass is attached to it? Explain why (0,0) is not a point on your graph. Now draw a best fit line.	For the more advanced students, this graph leads to students thinking about not including the origin, and ultimately about why the slope is the same but the intercept is different. The questions here are designed to let students recognise qualitatively that the slope of the two graphs are the same, but the intercepts are different. This was well beyond the grasp of most students and they did not see the relevance of this to the experiment. They felt that it was repetitious.

Appendix B (ii) Elements of inquiry, the language used in the classroom and teacher's comments: Topic 1.

Topic	Prerequisites	Elements of inquiry (verbal)	Elements of inquiry (experimentation)	Difficulty with Language	Change in language	Teacher comments
Spring Balance	Graphing, difference between mass and weight.	Springs in everyday life, opposing forces.	Find extension of spring and find this to be largely proportional to the weight added.	When the spring gets longer, it pulls harder. Extension versus extended length Best fit line	Elastic to "stretchy" (of spring) Steepness instead of slope (of line)	Post intervention: Students found language difficult. They found a lot of the work repetitive although this did not improve their understanding. [Remove one set of graphs]. Too long for the amount of course covered. Teachers in general overwhelmed and did not implement inquiry well.

Appendix B (iii) Rationale associated with homework questions.

	Question	Rationale
HW 1	Springs are used in everyday life. Give an example of where have you seen springs used. In this example, what made the spring useful?	This question aims at integrating students’ knowledge of the world and allows the student to think again or themselves.
HW 2	Answer the following questions on forces: a. What is meant by the term “force”? b. In what unit is force measured? What abbreviation is used for this unit?	These were lower order questions to establish if the student has listened and heard the prerequisites for completing the topic.
HW 3	A block with a mass of 360 g is hung on a spring. a. How big is the force of gravity the Earth exerts on the block? Show your work. b. How big is the force of the spring exerted on the block? Explain how you know. c. If you brought the block and spring to the Moon, would the force be greater, smaller, or the same? Explain.	Part a is a simple application of $F=mg$. Part b required students to think about balanced forces. Part c involves relating weight to the force exerted. This question refers to other learning outcomes in the syllabus.

Appendix B (iii) (continued) Rationale associated with homework questions.

	Question (continued)	Rationale (continued)
HW 4	What equipment did you use in the experiment, and how did you use it?	Students recall the experiment.
HW 5	A student has collected data for two different springs in an experiment similar to yours. [Table included here]. a. Plot a graph for the extension versus force applied on the graph on the next page for each spring. Clearly label both lines. b. Does one of the springs appear to be “stretchier” than the other one? If so, state which one and why. c. What does the steepness of the line tell you about the spring?	Part a gives students practice drawing graphs. One important use is to link a graph to what goes on in the lab. The students have no difficulty observing and knowing that one spring is “stretchier” than another but all had difficulty with part b and c.
HW 6	Attaching an object with a mass of 250 g to a certain spring makes it extend by 10.0 cm. By how much would the spring extend if you attached a different object with a mass of 100 g? Show your work.	The question is an application of Hooke’s Law. Proportional reasoning is encouraged, but many students who are adept at mathematics will choose an algebraic solution although this is less desirable.

HW= homework.

Appendix B (iii) (continued) Rationale associated with homework questions.

	Question (continued)	Rationale (continued)
HW 7	In the experiment of homework question 6, the student also measured the length of the springs. The data are given in the table below. [Table included]. a. On the graph on the next page, plot the length of the spring against force applied. Use the same number of boxes per cm as before. Use the data from Table 1. Do not draw a line yet. b. When there is no force applied, what is the extension of your spring? c. Now draw a best-fit line in your graph. d. Is the slope of this line steeper, less steep, or as steep as the slope of the line in homework question 6? Try to explain why that is so. What is different about the two lines?	The value of this question is much greater with students in second or third year. First years do not have enough experience with graphs to answer these questions unaided. it is hoped that students will recognise that it is the slope that matters, not whether the line goes through the origin or not.

HW= homework.

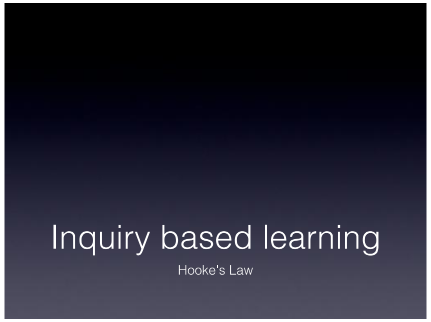
Appendix B (iv) Rationale associated with analysis.

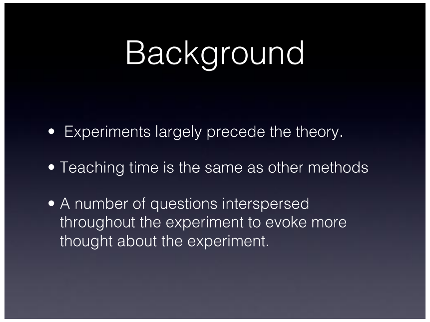
	Question	Rationale
Analysis 1	Take the point on your graph that is on the second thick vertical gridline. This point tells you what the extension of the spring is when it applies a certain force. How big is this force, and what is the extension of the spring when it applies that force? Explain how you could tell from your graph.	The level of difficulty of this question depends on how much the students already know about slopes and graphing in general. The question allows students to discover Hooke's Law. We have chosen to leave naming the relationship or law until after the students have discovered it for themselves. [The student's statement is called Hooke's Law].
Analysis 2	How big a force does the spring apply when the graph is on the fourth thick vertical gridline? And what is its extension then? How big a force does the spring apply when the graph is on the sixth thick vertical gridline? And what is its extension then?	
Analysis 3	A student says: "A spring will have twice the extension if twice the force is applied, 3 times the extension if 3 times the force is applied, and so on…"Is the student right? Explain how you can tell from your graph.	

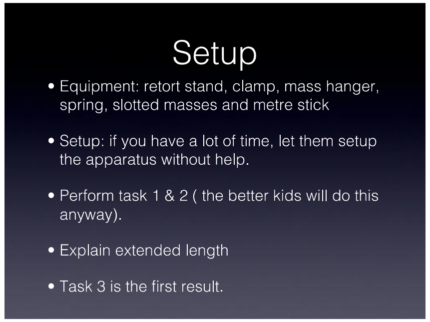
Table B (v) Rationale associated with post-test.

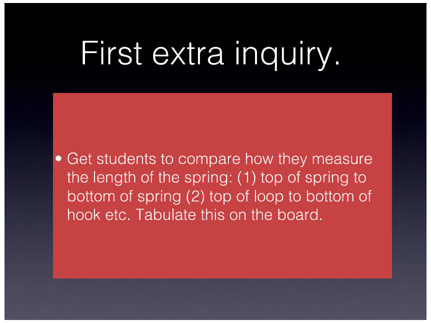
	Question	Rationale
Post-1	Using the experiment you have just finished, how would you find the mass of a set of keys?	This recall question required the student to apply the experience that they had acquired during the experiment. They would have drawn the graph from the table where they noted the extension of the spiral spring for the relevant weight in Newtons. They would then find the extension that the chosen object would have given. From the graph they would calculate the weight of that object.
Post-2	When measuring the extended length of a spring, does it matter if it is measured from the top of the spring to the bottom of the spring or from the loop on the top of the spring to the loop on the bottom of the spring? Why?	This question tested the student's understanding of extension versus extended length. Although this concept is reasonably easy, the language was difficult for first years.
Post-3	If the gravity on the moon is 1/6 of that on Earth, what would the weight of a 60g object be on the moon?	This question required two calculations: firstly, that weight and mass are not the same thing and secondly that only at this stage was it required to divide the answer by 6. This question did not relate directly to the experiment. The students would have learned the difference between gravity on earth and gravity on the moon and that mass and weight were different. First years find this more difficult than second years.
Post-4	Where on the graph would you place a mass of 10g on the graph above?	This was a higher order question. Students would have to convert grams into kilograms and then to Newtons. They then had to place the weight at a point below the lowest point on the graph they had drawn.
Post-5	Explain why do you think the graph above levels off?	The student needed to understand that the spring had been stretched beyond its elastic limit and an ability to understand the graph. The students would have observed this during the course of the experiment, as at least one student will have caused this to happen (higher order question).

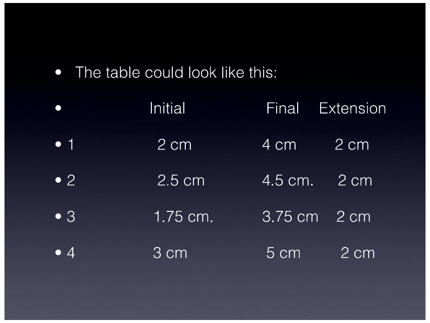
Appendix B (vi) Topic 1Presentation to teachers.

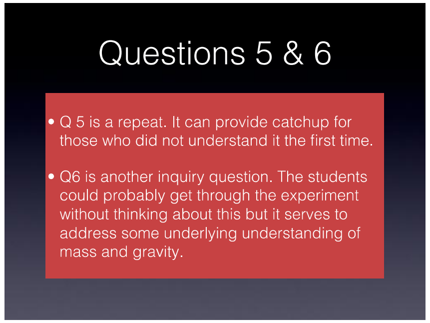












Mass force gravity

- After Q 6 is a good time to introduce this. The students have had time to be uncomfortable about how and why there is a pull on the spring and are likely to be more attentive.

measure extension when applied to different forces.

- The strong students will happily write down how they would measure the extension of the spring although this will challenge the weaker ones. This is a good exercise as some of the questions on the JC paper will require them to do this for a few experiments.

Q 8: Set up experiment and complete table

- The general view is that this is the start of the experiment.
- The formalisation of the prior steps may help the weaker student.

Q9 & 10: The graph

- The students FINALLY see the fruits of their labours!
- (I will put in a graph with line through zero here)

Q 12: regraphing

- This refines the students' understanding of graphing many will think they have got it "wrong".

over the challenge to them. As with all methods, some will love this and others will hate it. For the good student, the expectation is that the method will increase

Appendix B (vii) Physics Topic Lesson Plans

Name: ______________________________ Class: _____

Experiment: Making a spring balance

Optional questions are printed in **bold**.

In this experiment, you will investigate how a spring extends (gets longer) when different masses are hung from it.

1. Pick up the spring, and hang different masses on it. What do you notice?

____

____

____

____

____

2. Draw the spring below in two different situations: (a) when no mass is hanging on it, and (b) when there is a mass hanging on it.

   In diagram (b) below, indicate by how much the spring has stretched.

(a) no mass hanging from the spring	(b) mass hanging from the spring

Name: ______________________________ Class: _____

Experiment: Making a spring balance

Optional questions are printed in **bold**.

In this experiment, you will investigate how a spring extends (gets longer) when different masses are hung from it.

1. Pick up the spring, and hang different masses on it. What do you notice?

   ____

   ____

   ____

   ____

   ____

2. Draw the spring below in two different situations: (a) when no mass is hanging on it, and (b) when there is a mass hanging on it.

   In diagram (b) below, indicate by how much the spring has stretched.

(a) no mass hanging from the spring	(b) mass hanging from the spring

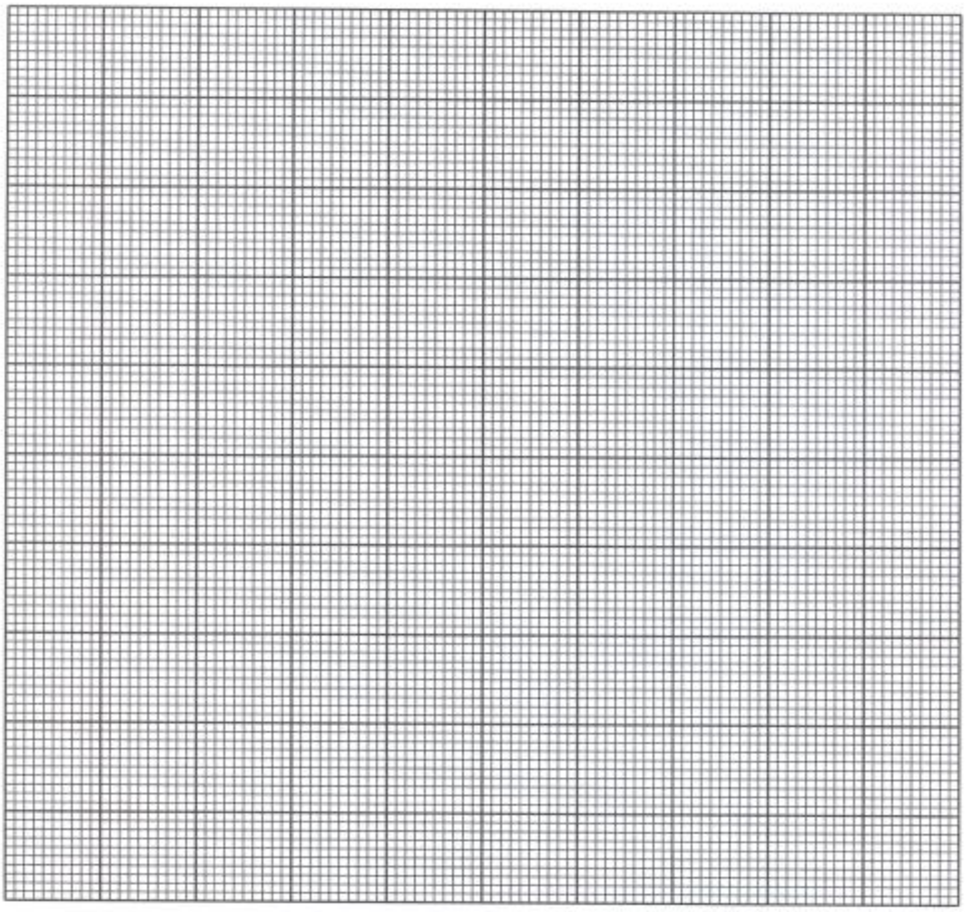
7. Look at the set-up shown in the diagram. How could you use it to measure how the extension of the spring changes when it applies different forces?

8. Set up the experiment, and make measurements that allow you to complete Table 1. You should make a measurement for each mass you add to the spring. If you are not sure of the mass of the hanger or the disks, ask your teacher. Remember that for every 100 g there is a force of about 1 N due to the pull of the Earth.

Table 1: The length of the spring for each mass added and the extension of the spring.

	spring only	spring with hanger	1 disc added					
total mass added (g)	0							
applied force (N)	0							
length (cm)								
extension (cm)	0							

9. Plot a graph for the **extension** (**not** the length) of the spring against the force applied. Plot the force on the horizontal axis, the length on the vertical axis.



10. Remove the mass hanger, and hang an object such as a set of keys or a heavy pen on the spring. Measure the length and extension of the spring and then fill in your results in Table 2.

Table 2: The length of the spring and its extension for the object you added.

object	length (cm)	extension (cm)

Use your graph on the previous page to determine the force the spring exerts on the object you hung on it.

____

____

Determine the mass of the object. Show your work.

____

____

11. Measure the mass of the same object with a mass balance. How does the value compare to yours?

____

____

12. **On the next page, plot a graph for the** length **(not the extension) of the spring against the force applied. Plot the force on the horizontal axis, the length on the vertical axis.** Do not yet draw a best fit line.

What is the length of the spring when no mass is attached to it?

____

Explain why (0,0) is not **a point on your graph.**

____

Now draw a best fit line.

Homework Questions

1. Springs are used in everyday life. Give an example of where have you seen springs used.

   ____

   ____

   In this example, what made the spring useful?

   ____

   ____

2. Answer the following questions on forces:

   a. What is meant by the term "force"?

   ____

   ____

   b. In what unit is force measured? What abbreviation is used for this unit?

   ____

3. A block with a mass of 360 g is hung on a spring.

   a. How big is the force of gravity the Earth exerts on the block? Show your work.

   ____

   ____

   ____

   b. How big is the force of the spring exerts on the block? Explain how you know.

   ____

   ____

   ____

   c. If you brought the block and spring to the Moon, would the force be greater, smaller, or the same? Explain.

   ____

   ____

   ____

4. What equipment did you use in the experiment, and how did you use it?

5. A student has collected data for two different springs in an experiment similar to yours.

applied force (N)	0.5	1.0	1.5	2.0	2.5	3.0
extension of spring 1 (cm)	2.0	4.0	6.0	8.0	10.0	12.0
extension of spring 2 (cm)	3.0	6.0	9.0	12.0	15.0	18.0

a. Plot a graph for the extension versus force applied on the graph on the next page for each spring. Clearly label both lines.

b. Does one of the springs appear to be stretchier than the other one? If so, state which one and why.

What does the steepness of the line tell you about the spring?

6. Attaching an object with a mass of 250 g to a certain spring makes it extend by 10.0 cm. By how much would the spring extend if you attached a different object with a mass of 100 g? Show your work.

7. In the experiment of homework question 6, the student also measured the length of the springs. The data are given in the table below.

applied force (N)	0.5	1.0	1.5	2.0	2.5	3.0
length of spring 1 (cm)	8.2	10.2	12.2	14.2	16.2	18.2
length of spring 2 (cm)	8.9	11.9	14.9	17.9	20.9	23.9

a. **On the graph on the next page, plot the** length **of the spring against force applied. Use the same number of boxes per cm as before. Use the data from Table 1.** Do not draw a line yet.

b. **When there is no force applied, what is the extension of your spring?**

____

c. **Now draw a best fit line in your graph.**

d. **Is the slope of this line *steeper, less steep,* or *as steep as* the slope of the line in homework question 6?**

____

____

Try to explain why that is so.

____

____

What is different about the two lines?

____

____

____

Analysis: Making a spring balance

1. Take the point on your graph that is on the second thick vertical gridline. This point tells you what the extension of the spring is when it applies a certain force.

   How big is this force, and what is the extension of the spring when it applies that force? Explain how you could tell from your graph.

   ____

   ____

2. How big a force does the spring apply when the graph is on the fourth thick vertical gridline? And what is its extension then?

   ____

   ____

   How big a force does the spring apply when the graph is on the sixth thick vertical gridline? And what is its extension then?

   ____

   ____

3. A student says:

   > *"A spring will have twice the extension if twice the force is applied, 3 times the extension if 3 times the force is applied, and so on..."*

   Is the student right? Explain how you can tell from your graph.

   ____

   ____

   ____

The student's statement is called Hooke's Law.

6. **Is an application of Hooke's Law. Proportional reasoning is to be encouraged, but an algebraic solution is also fine.**

7. **The questions here are designed to let students recognise qualitatively that the slope of the two graphs are the same, but the intercepts are different. (However, if asked for a quantitative determination of the slope, many students will divide the two coordinates rather than calculate rise-over-run.) Hence, it is hoped that students will recognise that it is the slope that matters, not whether the line goes through the origin or not.**

Analysis: Making a spring balance

This is a tutorial style 40 minute class to follow the experiment and homework.

8. The level of difficulty of this question depends on how much the students already know about slopes and graphing in general. The question allows students to discover Hooke's Law for themselves. As often, we have chosen to leave naming the relationship or law until after the students have discovered it for themselves.

Appendix C: Topic 2: Biology

Appendix C (i) Elements of inquiry, the language used in the classroom and teacher's comments: Topic 2.

42

Topic	Prerequisites	Elements of inquiry (verbal)	Elements of inquiry (experimentation)	Language Difficulty	Change in language	Teacher comments
Flowering plant	None	Do plants drink water? Where do plants get their water? How do you think water travels around a plant? Do you think plants breath? Where and how do they store food?	Observation and pointing out similarities and differences. Students to devise own experiments	Xylem phloem Stereoscope, transparent Vaseline	Explain, no change	Pre intervention: All teachers felt this was too long. . Do not include photosynthesis. Post intervention: Teachers enjoyed the inquiry aspect of this topic although they found it difficult not to give answers but to prompt students instead.

Appendix C (ii) Priming questions added to teachers' guidelines.

Pre-test

1) Do plants drink water?
2) What aspects of all plants are the same?
3) Where do plants get their water?
4) How does water travel around a plant?
5) Where do plants get their food?
6) Where do they store food?
7) What happens if plants are kept in the dark?
8) What happens if there is no CO_2 available to plants?
9) Can plants survive without O_2?

(Given a number of plants) ARE ALL PLANTS THE SAME?

(Given a number of plants) WHAT ARE THESE? WHAT DID I HAVE TO DO TO GET THESE?

(Given seedlings). HOW DID I GROW THESE?

Ask students to devise experiments to determine...... (different plant functions).

Get students to observe (different parts of different plants

Have the students look at the roots and root hairs and the stomata on the underside of the leaves

Report back to the group

Get each student to bring in mosses, ferns, conifers, monocots and dicots as they have to think to be able to do this correctly. It is *not* a case of recall. The purpose of this is to have them use all they have learned in class in a real life situation, *deducing* how these plants are classified.

How would you set up an experiment to find out which part of the plant transpires most given a large plant, transparent plastic bags, string and some Vaseline

Appendix C (iii) Topic 2: Final Draft

OB45 Identify the main parts of a typical flowering plant and their functions; the root, stem, leaf and flower

OB 46 Understand that the xylem transports water and minerals in the plant and that the phloem transports food

OB 47 Carry out simple activities to show the path of water through plant tissue, and show that water evaporates from the surface of a leaf by transpiration

This unit contains elements of inquiry – students are asked to devise and carry out some experiments.

Inquiry is in RED.

Preparation: Grow seedlings, collect of a variety of mono and dicot plants.

Some questions that may promote inquiry during the unit (the students should be encouraged to find the answers for themselves with a little prompting from the teacher):

1) What parts of all plants are the same?
2) Why do you think a plant needs roots?
3) Do plants drink water?
4) Where do plants get their water?
5) How do you think water travel around a plant?
6) Do you think plants breathe?
7) Where and how do they store food?

Class 1

Level: 1st Year, 2nd Year, 3rd Year
Duration: 40 minutes (single class)
Prerequisites: nothing especially.
Preparation: grow seedlings; bring mosses, ferns, conifers, monocots, dicots to class

Structure:

1. ARE ALL PLANTS THE SAME? (Power point).

2. Have various examples of plants. Name the parts. Include mosses, ferns, conifers, and flowering plants. WHAT ARE THESE? (part memory from PP, part deduction)

3. Hand out seedlings and get students to examine. HOW DID I GROW THESE? Draw and label the parts.

4. Ask students to devise experiments to determine (a) the function of the different parts of the plants and write them down and (b) to determine the answer to the following questions: *do the roots, the shoots, or both absorb water?*

5. Collect list of experiments to be carried out in Class 3.

Class 2, 3.

Level: 1st Year, 2nd Year, 3rd Year
Duration: 80 minutes (double class)
Prerequisites: Class 1
Preparation: Bring mosses, ferns, conifers, monocots, dicots to class. Bring in busy lizzy, celery, seedlings, test tubes, dye, water, oil

Structure:

1. Briefly get students to observe again four different plants: (1 moss, 1 fern, 1 monocot and 1 dicot) and look for similarities (in the leaf stem and root structure).

2. To get a closer look using a stereoscope, magnifiing glass or electronic magnifier have the students look at the roots and root hairs and the stomata on the underside of the leaves.

3. Set up and ask for predictions with suitable controls (continuation from 4 in class 1):

Busy lizzy in dye, celery in dye (to observe that water is taken up by the roots and that it is carried in structures called xylem)

Potted plant with transparent plastic bag over it. (OPTIONAL) Place sensors to measure humidity. Carbon dioxide and oxygen sensors are optional. (Let different groups use different sensors and report back to the group)

Plant out of water to show that water is absorbed through the roots.

Plant with roots in water, covered with oil to show that water absorbed through the roots escapes through the areal parts of the plant and that the decrease in the water level is not due to evaporation. Place sticks of celery in water mixed with food dye.

Plant with some of its leaves tied in transparent plastic bags. The intention of this experiment is to show that transpiration principally occurs in the leaf. It is also a hint towards how they should perform the post-test/ higher order question.

Class 4.

Level: 1st Year, 2nd Year, 3rd Year
Duration: 40 minutes (single class)
Prerequisites: Class 2 & 3
Preparation: Prepared experiments from previous class.

Structure:

1) Get students to visually evaluate the progress of the experiments they set up the previous class.

2) Discuss their finding with their group.

3) Report to class.

4) Teacher modification of evaluation through questioning.

5) Write a report to include this evaluation.

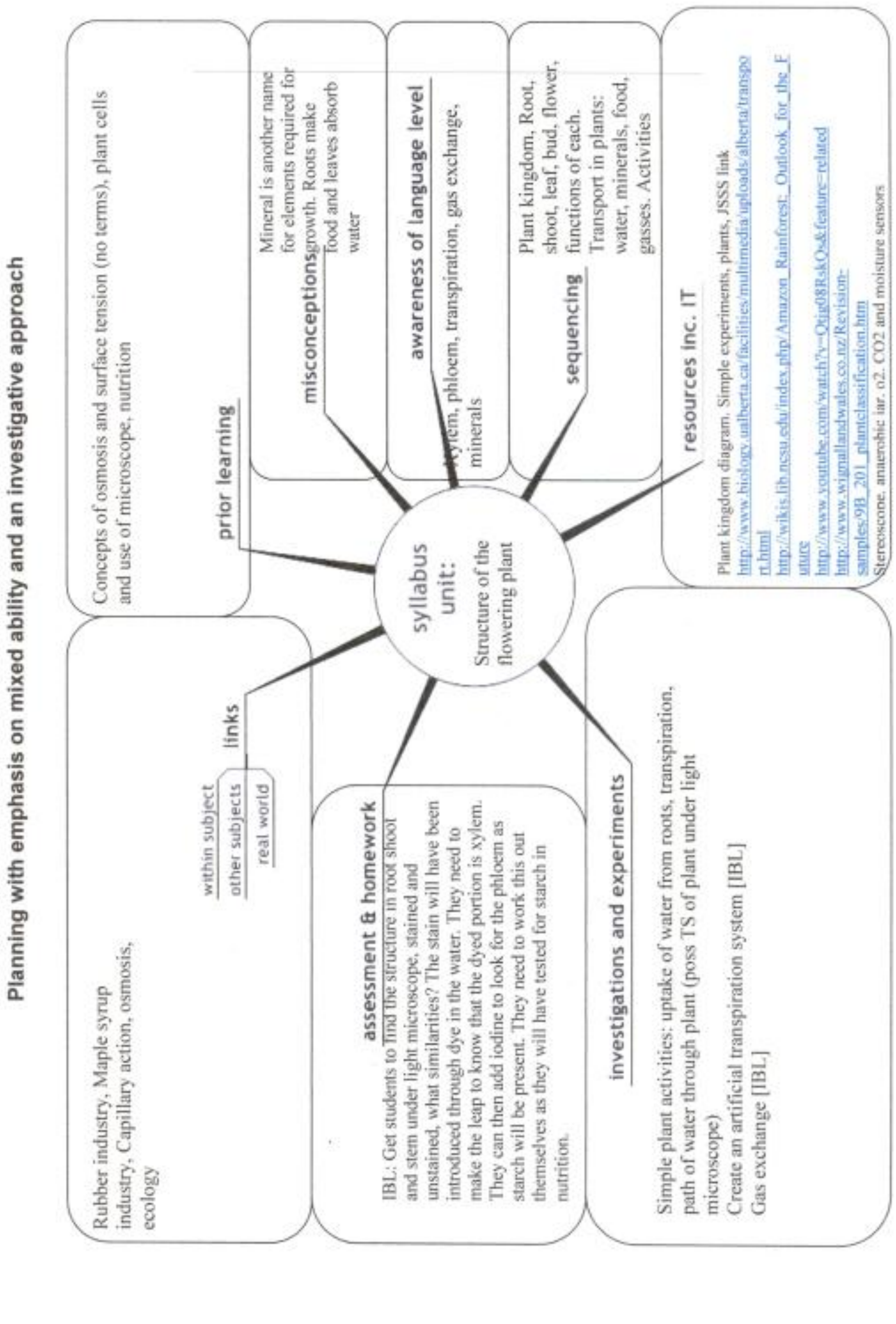
Higher order/ post-test question

How would you set up an experiment to find out which part of the plant transpires most given a large plant, transparent plastic bags, string and some Vaseline.

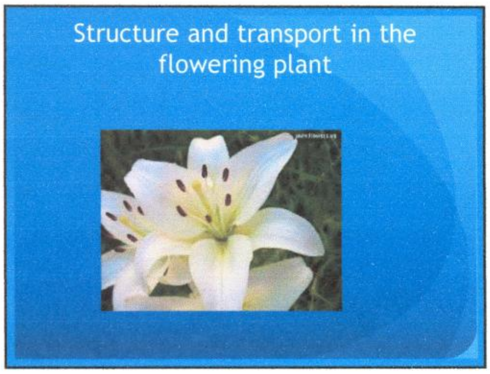
Appendix C (iv) Teachers' view of Topic 2.

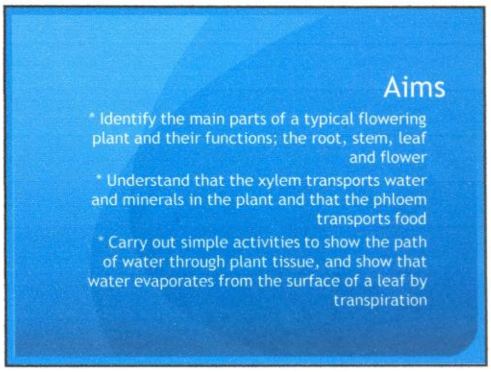
Teacher	What aspects of each class would you change, and what would you do instead?
1	Would not use plant kingdom structure. Would not use sensors [hate them] but willing to try. By class 2, would have already. Done seedlings in oil. TS work is covered at L.C. So would not do it here. Would not have done stereoscopic view of roots due to constraint with materials. Remember to mark the water level in seedling. Class 4: challenge too advanced. Osmosis done at LC
2	First class is too short for all required. T.S and sensors too much for JC. Can speed up transpiration with hair dryer. Do slide dying as IBL
3	Sensors? Would like to learn.
4	Class 2 is too long. Did not understand class 4, need some help with it. Help with sensors, do we have enough?
5	TS section is LC. Remove anaerobic jar. Get them to look at stomata (like the mouth of the plant). Do male and female plants. Bring in seaweed, conifers, moss, algae Add extra IBL: monocot vs dicot. Woody vs Herbaceous Veins in leaves are transport tissue. Would not do artificial plant: too advanced
6	No longer participating.
Teacher	How many classes do you think it will take to cover this material?
1	5 to 6 classes
2	The number suggested.
3	4 to 5
4	Normally takes 4 periods
5	4

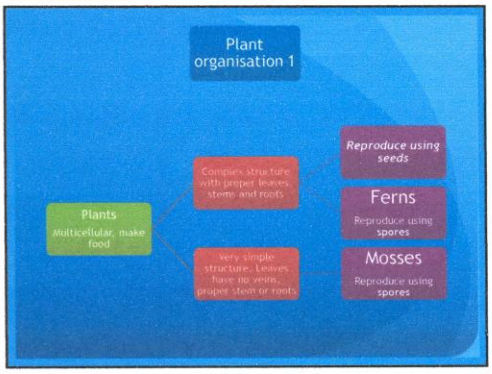
Appendix C (v) mind map to develop biology topic.

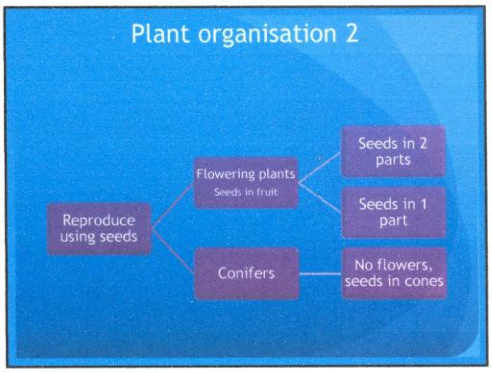


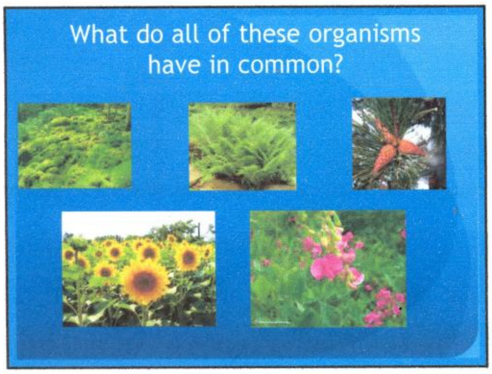
Appendix C (vi) Topic 2: Presentation from teachers to class.

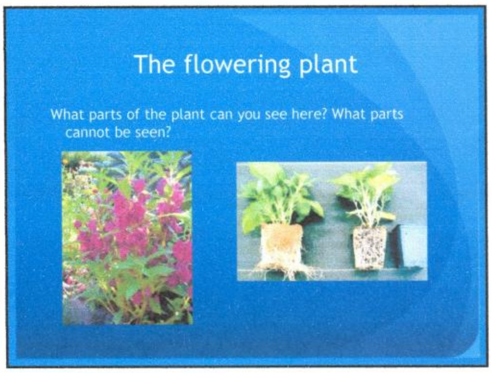


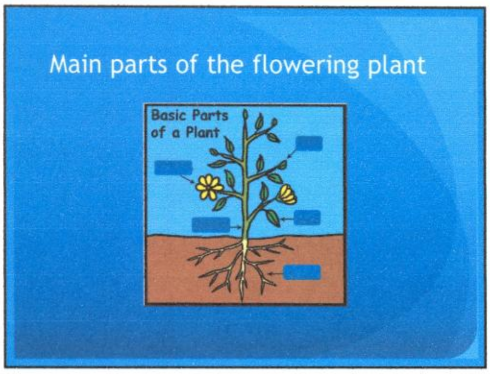


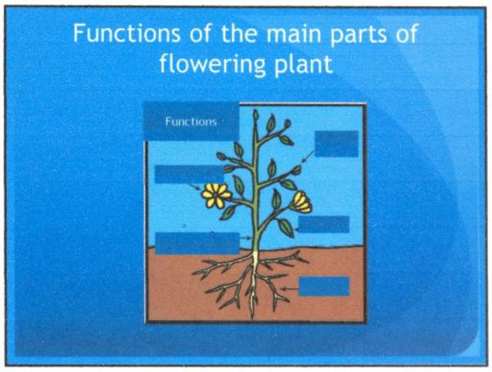


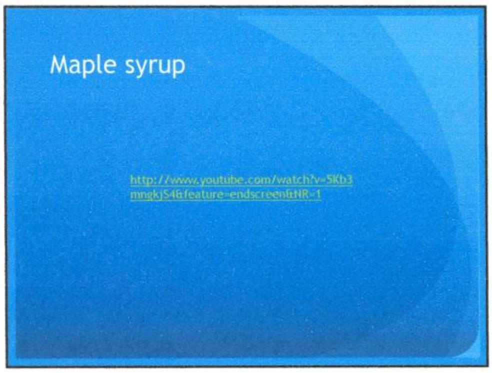


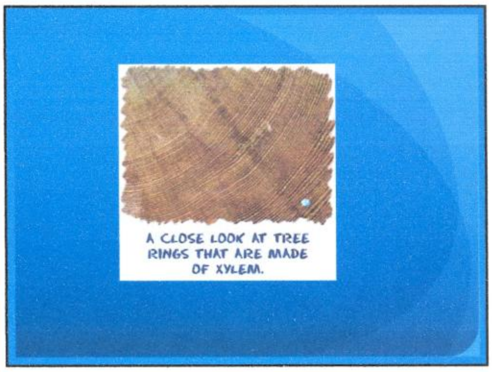


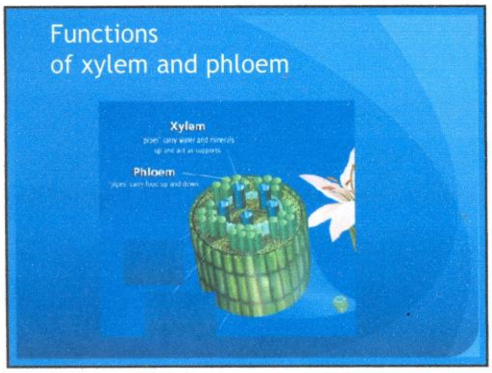


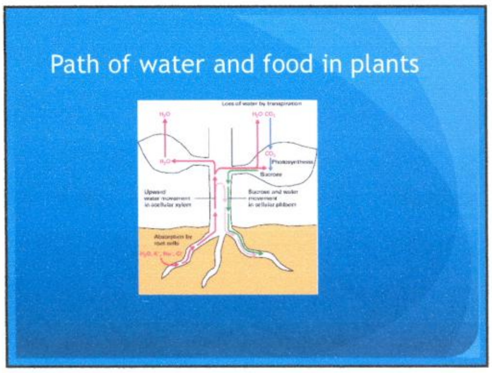

Main parts of the flowering plant
Basic Parts of a Plant


Functions of the main parts of flowering plant
Functions


Maple syrup
http://www.youtube.com/watch?v=5Kb3mngkjS4&feature=endscreen&NR=1


A CLOSE LOOK AT TREE RINGS THAT ARE MADE OF XYLEM.


Functions
of xylem and phloem
Xylem
Phloem


Path of water and food in plants

Appendix C (vii) Topic 2 Resources.

Stereoscope

Transpiration experiment

Appendix C (viii) Data to Support Figures 4.4 and 4.5

Students' view of the difficulty of the biology topic stratified by teacher

Biology	Easy %	Neither easy nor difficult %	Difficult %
T1 n= 15	47	27	27
T2 n= 18	28	56	17
T3 n= 13	31	38	31
T4 n= 11	18	82	0
Total n= 57	31	50	19

Students' view of the enjoyment of the biology topicstratified by teacher

Biology	No enjoyment	Neither enjoy nor not enjoy %	Enjoy %
T1 n= 15	50	40	20
T2 n= 18	50	11	39
T3 n= 11	18	27	55
T4 n= 11	0	45	55
Total n= 55	31	29	40

Appendix D: Topic 3 Chemistry

Appendix D (i). Elements of inquiry, the language used in the classroom and teacher's comments: Topic 3.

Topic	Prerequisites	Elements of inquiry (verbal)	Elements of inquiry (experimentation)	Language Difficulty	Change in language	Teacher comments
Chemical bonding	Periodic table, Bohr model of atom, Octet rule.	Using inquiry deduce which are covalent bonds and which are ionic bonds.	What atoms do you think would be more reactive and why? [using magnetic models]	Ionic, covalent.	"giving, sharing"	Pre intervention: Not enough time allotted to differentiating between ionic and covalent boding. Students need time to practice. Post intervention: Found method useful, both teachers and students engaged well

Appendix D (ii) Priming questions added to teachers' guidelines.

Aspects of inquiry based learning (IBL) that are used in this unit:

Class 1: using models of atoms get class to demonstrate why group 8 atoms are un-reactive

Class 2: using models of atoms, which atoms are likely to be more reactive than others?

Class 3. Knowing that the octet rule must be obeyed, describe how they think sodium and chlorine would form a molecule, how would this be described? [follow with HF, KCl, MgO]

Class 4: What happens to the hydrogen when it bonds with chlorine?, What happens to the sodium when it bonds to fluorine? Imagine if there were lots of sodiums and lots of chlorines what might happen?

Class 5: Repeat class 3 with methane, hydrogen molecule, carbon dioxide, oxygen gas. Describe the type of bond.

Class 6: Repeat class 4

Class 7: Have the class to create their own 'disco drama' where they label themselves as different elements and associated electrons and have them to make molecules by pairing.

Class 8: what are the properties associated with ionic compounds and then with covalent compounds.

Class 9: Which types of compounds conduct electricity and why?

Appendix D (iii) Topic 3 Final Draft

Dear Teachers

Having taken into consideration all the comments made by the contributing teachers, this is the revised module that I would like you to teach. When you have done so, I would appreciate if you would give me feedback with a questionnaire I will provide.

These are some of the comments that you made:

Isotopes do not ‘sit well’ in this unit. They are normally covered before this.

Not enough time allocated to teaching ionic and covalent bonding. At least twice the time should be allocated to this.

Two teachers use a fun method to explain the difference between covalent and ionic bonding “going to the disco”.

Another teacher uses cardboard rings and play dough to help visualize the atoms and how they bond. This is a much cheaper option than magnetic models.

Another has a power point presentation that he has made available to me.

There are many worksheets and home work sheets attached. It is not necessary to use all of these. Some have been downloaded from the JSSS website.

Remember, it is important to incorporate your own teaching style in this unit insofar as that you ensure that they find out or attempt to find out using the inquiry method as is set out in the units. It is also important that there is a period at the end of each class where the teacher clarifies what has hopefully been learned by summarizing the findings of the class.

Yours sincerely,

Katie Corbett

First class (40 mins)

Class resources:

Periodic table, either magnetic board game or cardboard rings with play dough, Worksheet A and homework B

Schedule

Revise periodic table, structure of the atom, location, relative charge and relative atomic mass of the subatomic particles, atomic number and mass number.

Next introduce the octet rule and valence.

Next use Magnetic Bohr model sets in groups of three. Get the pupils in their groups to make Group 8 models.

IBL: In light of what you have learned about valence and the octet rule, how reactive do you think these group 8 atoms are?

Wrap up: they need to know that group 8 atoms are un-reactive and why.

- Worksheet to support the above activity **Worksheet A**
- Homework **Worksheet B**

Second class (40 mins)

Class resources: Periodic table, either magnetic board game or cardboard rings with play dough, Worksheet C

Schedule

This may be the second part of a double class. Recap on the previous activity. Repeat the previous activity except, this time introduce groups 1, 2, 7. Later let them construct oxygen, nitrogen, carbon.

IBL: In light of what you have learned about valence and the octet rule, how reactive do you think group 1, 2, 7 atoms are? How reactive are oxygen, nitrogen, carbon compared with chlorine or hydrogen. How reactive are any of these compared with helium, neon or argon?

Wrap up: they need to know that groups 1, 2 and 7 are more reactive than the groups that contain O, N and C. They need to know the names of the different groups.

• Worksheet to support the above activity **Worksheet C**

Third Class

Class resources: Periodic table, either magnetic board game or cardboard rings with play dough, Worksheet (D).

Have the class in groups make a model of sodium chloride.

IBL: What way do you think the following atoms could be linked together: sodium and chlorine? The octet rule must be obeyed. What other atoms could you *combine in the same way*, obeying the octet rule: Suggest HF, KCl, MgO if necessary,

Wrap up: they need to know that when atoms 'give' or 'take' electrons to form a bond that this is known as ionic bonding.

Worksheet **D**

Fourth Class

Class resources: Periodic table, LOTS OF either magnetic board game or cardboard rings with play dough, Worksheet E.

In this class, the students should be guided to see that because of the polar nature of these molecules that different molecules can link together and so make lattices.

IBL What happens to the hydrogen when it bonds with chlorine?, What happens to the sodium when it bonds to fluorine? Imagine if there were lots of sodiums and lots of chlorines what might happen?

Wrap up: they need to know that lattices are formed and why.

• Homework **Worksheet E** is to reinforce class 3

Fifth Class

Class resources: Periodic table, either magnetic board game or cardboard rings with play dough, Worksheet (**Worksheet** F).

Have the class in groups make a model of methane.

IBL: What way do you think the following atoms could be linked together: carbon and hydrogen? The octet rule must be obeyed. What other atoms could you *combine in the same way*, obeying the octet rule. Suggest CO_2, H_2, N_2 if necessary.

Wrap up: they need to know that when atoms 'share' electrons then this is known as covalent bonding.

• Homework **Worksheet F**

Sixth Class

Class resources: Periodic table, either magnetic board game or cardboard rings with play dough.

Have the class attempt to make lattices with covalent compounds.

Wrap up: they need to know that covalent bonding does not result in lattice formation.

IBL What happens to the hydrogens when it bonds with carbon to make methane? Do you thin that methane molecules will interact?

Seventh Class

Class resources: Periodic table, sticky labels Worksheet G, H

Have the class create their own 'disco drama' where they label themselves as different elements and associated electrons and have them to make molecules by pairing.

Wrap up: they need to know the difference between ionic and covalent bonds and that covalent bonds are more stable.

- Worksheet **G**
- Homework **Worksheet H**

Class 8

Class resources: Periodic table, sodium chloride (ionic), corn oil (covalent) and other examples.

Have the class observe the physical state of the compounds. Add to water, observe what happens. Heat both and observe what happens. Have the students categorise the samples in terms of physical state, solubility in water and melting point.

Wrap up: they need to know the properties of ionic and covalent compounds

Class 9

Class resources: Periodic table, electric circuits: cables, battery, lamp, switch, beaker, solutions, electrodes. Worksheet I.

The class must predict which substances will conduct electricity and why.

Wrap up: they need to know that ionic solutions will conduct electricity and that covalent do not and why.

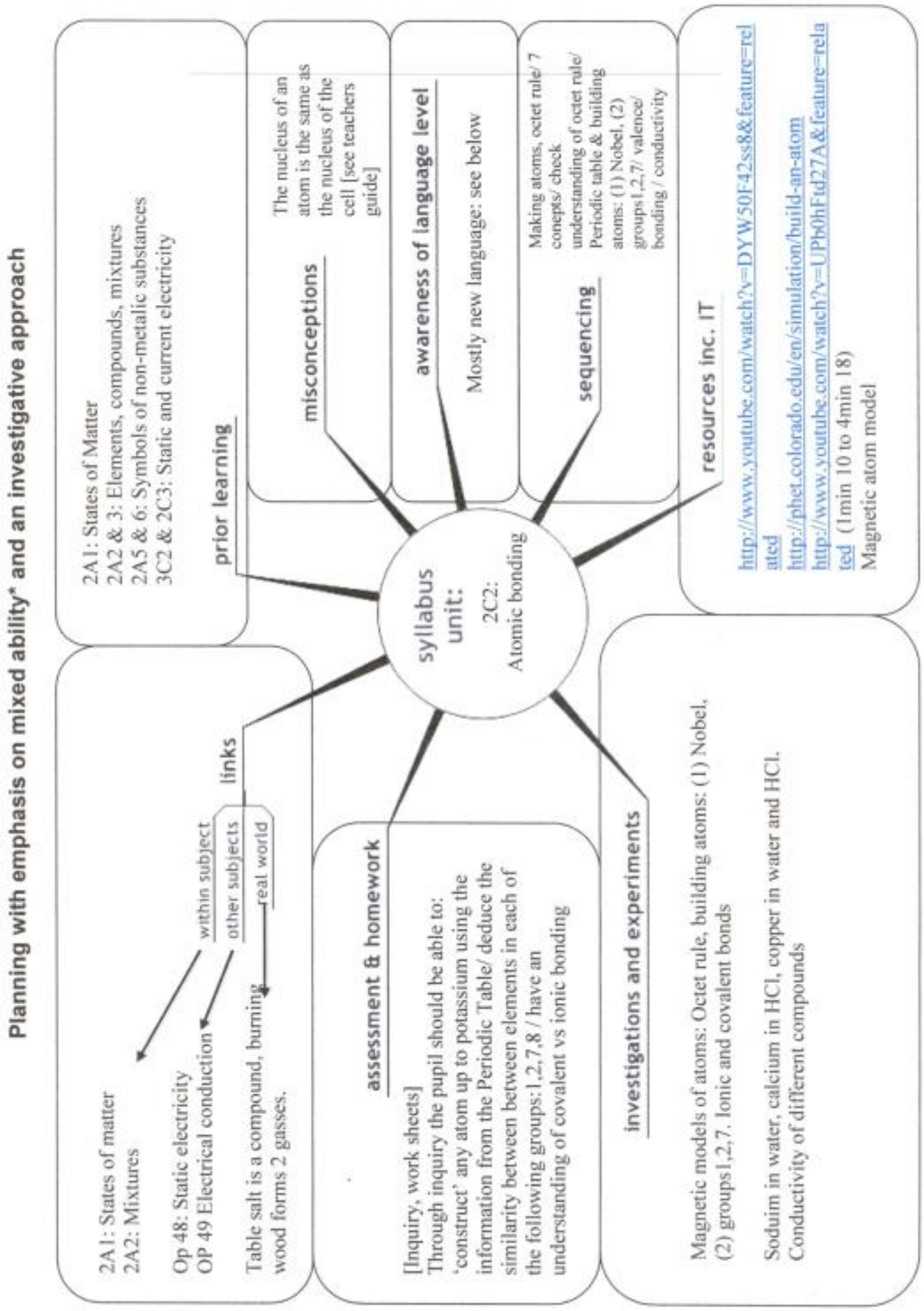
Post-test

- What makes atoms of different elements different from each other?
- In what ways do elements combine to make a molecule? Explain in your own words
- What way can elements be grouped?
- What type of bond does each of the following have? H_2O, MgO, CH_4, NaCl?
- If tap water was used in the conductivity experiment instead of de-ionised water would this change the conductivity of the water?
- Calcium can bond with chlorine to form calcium chloride. Do you think this bond is ionic or covalent? What do you think is the structure of calcium chloride? Explain. Categorise the following molecules as ionic or covalent: $CaCl_2$ $MgCl_2$, O_2, $Ca(OH)_2$, N_2, CH_4, C_2H_5OH.
- This is a chemical equation. Insert the correct numbers of each molecule to make the equation correct (balance).
- $Ca(OH)_2 + CO_2 \longrightarrow CaCO_3 + H_2O$

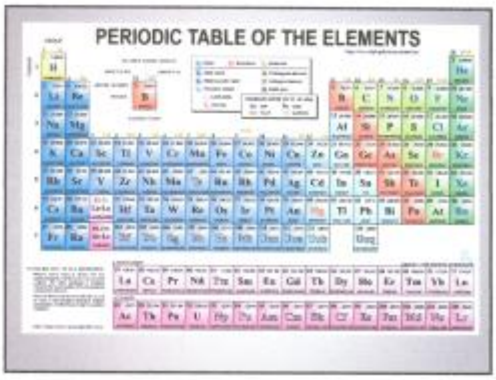
Appendix D (iv) Teachers' view of Topic 3.

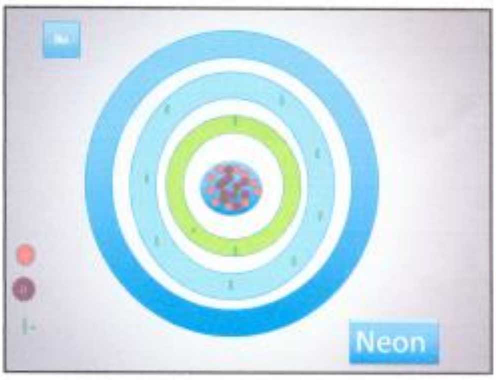
Teacher	What aspects of each class would you change, and what would you do instead?
1	Second class too long fifth class too short
2	[NOT ANSWERED]
3	NOTHING
4	IT’S FINE.
Teacher	How many classes do you think it will take to cover this material?
1	8
2	6
3	8
4	4

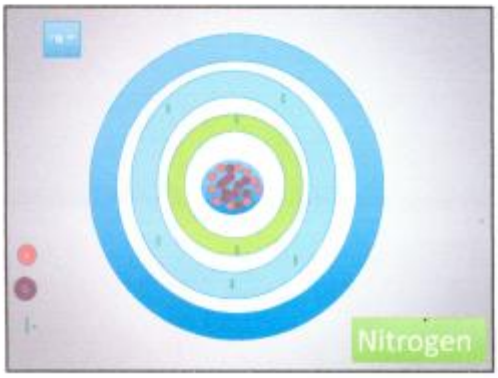
Appendix D (v) Topic 3: Mind map to develop chemistry.

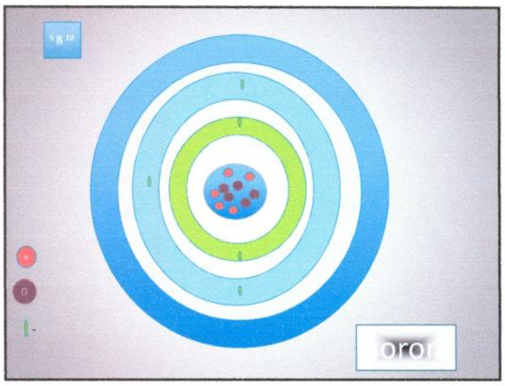
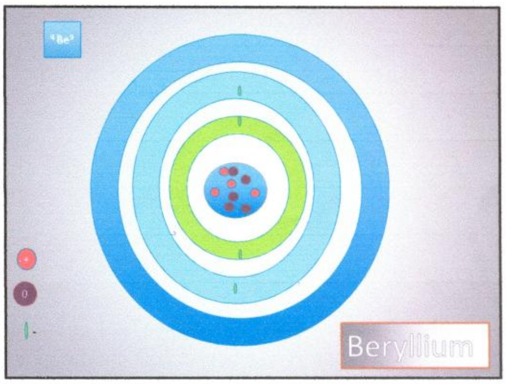
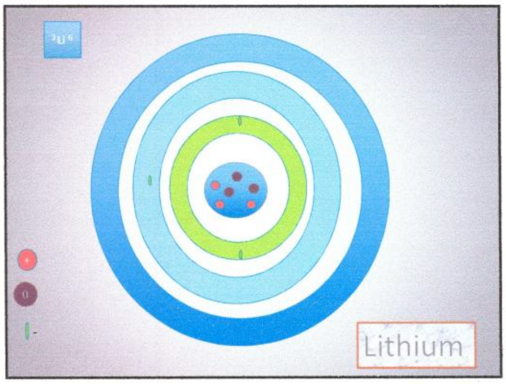
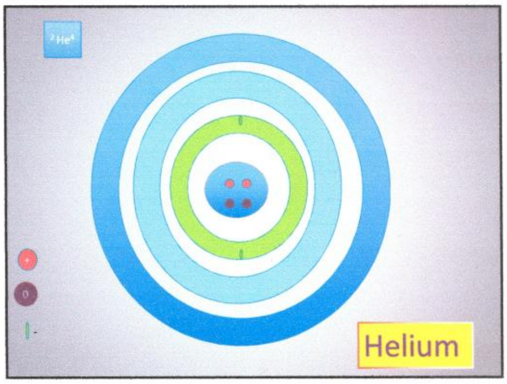
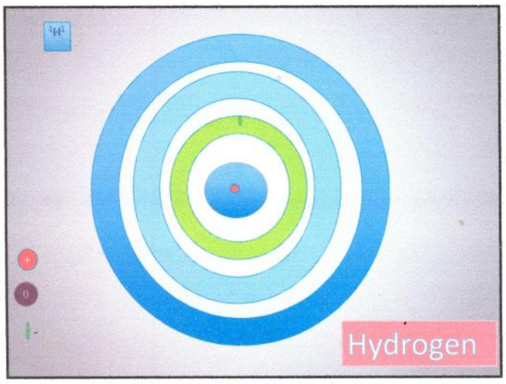
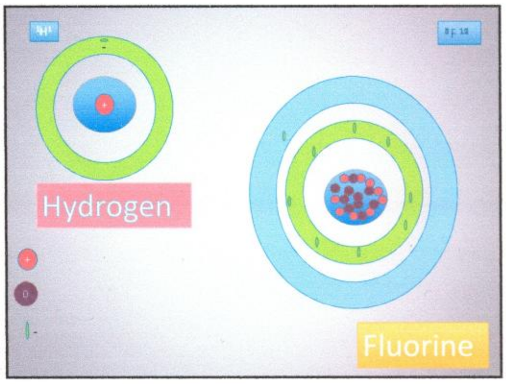


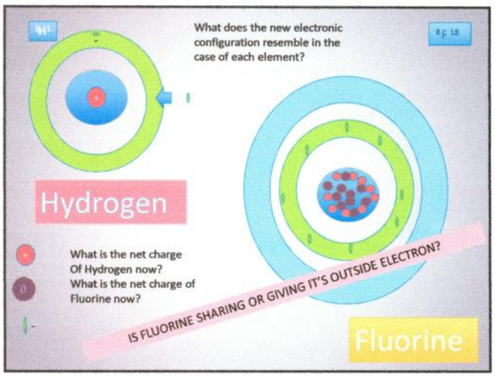
Appendix D (vi) Presentation from teachers to class Topic 3.

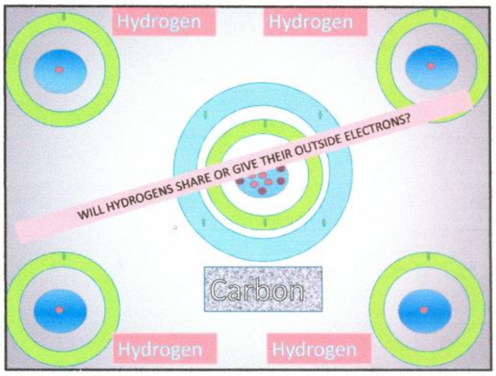




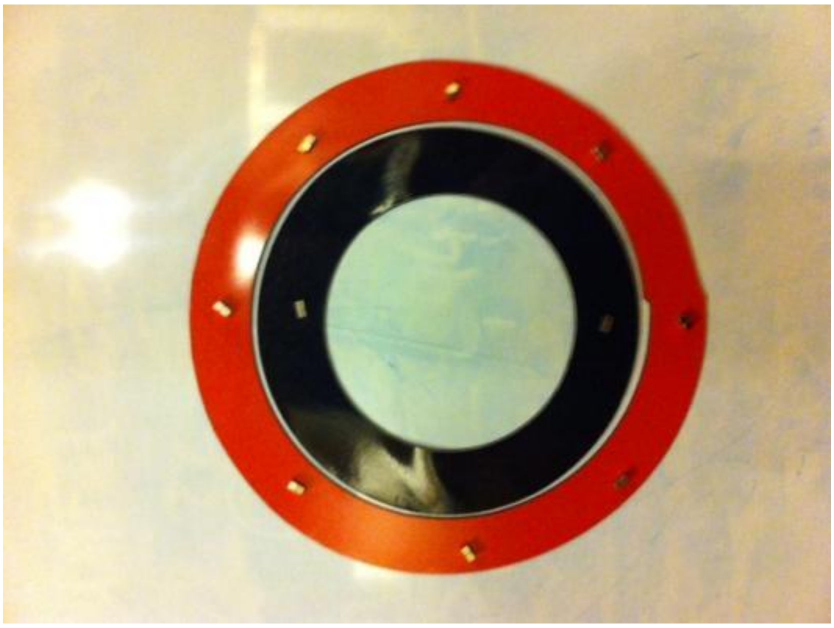



oron

Beryllium

Lithium

Helium

Hydrogen

Hydrogen
Fluorine

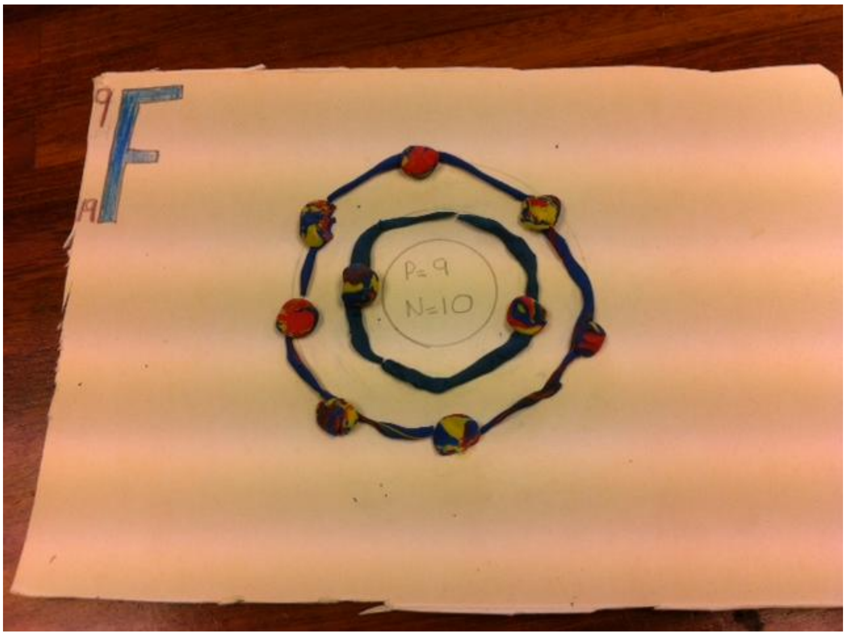

What does the new electronic configuration resemble in the case of each element?
Hydrogen
What is the net charge Of Hydrogen now?
What is the net charge of Fluorine now?
IS FLUORINE SHARING OR GIVING IT'S OUTSIDE ELECTRON?
Fluorine


Hydrogen
Hydrogen
WILL HYDROGENS SHARE OR GIVE THEIR OUTSIDE ELECTRONS?
Carbon
Hydrogen
Hydrogen

Appendix D (vii) Topic 2 Resources.



Bohr Model on magnetic Board



Bohr Model with modeling clay

Appendix D (viii) Data to Support Figures 4.6 and 4.7.

Students' view of the difficulty of the chemistry topic stratified by teacher

Chemistry	No enjoyment %	Neither enjoy nor not enjoy %	Enjoy %
T1 n= 17	17.5	65	17.5
T2 n= 20	40	45	15
T3 n= 15	20	80	0
T4 n= 11	9	45.5	45.5
Total n= 63	24	59	17

Students' view of the enjoyment of the chemistry topic stratified by teacher

Chemistry	Easy %	Neither easy nor difficult %	Difficu lt
T1 n= 17	0	18	82
T2 n= 20	10	55	35
T3 n= 15	20	53	27
T4 n= 11	18	64	18
Total n=63	11	46	43

Appendix E: Consent Forms

Appendix E (i) Teachers' informed consent to participate in the study.

LETTER TO TEACHERS (ON DCU HEADED PAPER)

Improvement of attitudes to science using inquiry based learning

Dear [Teachers' name],

Thank you for agreeing to participate in this study. I have enclosed a description of the study and a consent form for you to participate. I expect that the delivery of the modules will commence after the February mid-term and finish by 15th April before Easter holidays. All modules will not take any longer to deliver than normal.

After the Christmas break, the students will take home consent forms. They will be asked to return them to you. This is a tedious phase and I will make every effort to make sure this is not a burden to you. The students will each have a code with an X or a tick next to it. Those who wish to participate will have a tick and those who do not will have an X. They will all perform the same tasks but only those who have agreed to participate will have their results given to me. Before the module, they must fill out a survey on attitudes to science. I have included a copy of this survey also.

The first module will be Hooke's Law as this has already been finalised. Both Aidan and I have used this in the past. I will set up sessions with you all to demonstrate how it was run. I would like to discuss with you all which chemistry and biology modules would easily lend themselves to this method of teaching.

When all modules taught for the purpose of the study are complete, the students will once again fill out the attitude to science questionnaire again.

The study has been passed by the DCU ethics committee. Thank you for agreeing to participate although if for any reason you choose to opt out this is not a problem.

Your sincerely,
Dr Katie Corbett

Appendix E (i) (continued) Teachers' informed consent to participate in the study.

INFORMED CONSENT FORM *TEACHERS*

I. Research Study Title

Improvement of attitudes to science using inquiry based learning. The research is being carried out by Dr Katie Corbett, a post -primary teacher at Skerries Community College and is being supervised by Dr Paul van Kampen and Dr James Lovatt at Dublin City University.

II. Clarification of the purpose of research.

This research relates to the evaluation of inquiry based learning (IBL) within the Junior Science syllabus. The study expects to improve students' conceptual understanding and ability to learn by inquiry. The investigators also which to assess the impact of inductive learning has on students' interest in science. If this method is successful, then other modules will be taught in this manner.

It is intended to publish the results in an education research journal. All names will be confidential.

III. Confirmation of particular requirements as highlighted in the plain language statement.

To the Teacher:
Please read the following questions and circle either Yes or No

Have you read or had read to you the Plain Language Statement?	YES/ NO
Do you understand the information provided?	YES/ NO
Have you had an opportunity to ask questions and discuss this study?	YES/ NO
Have you received satisfactory answers to all your questions?	YES/ NO
Are you aware that the discussions/ interviews may be audio-taped?	YES/ NO

IV. Confirmation that involvement in the Research Study is voluntary.

Your involvement is entirely voluntary .You can withdraw from the study at any time.

V. Advice as to the arrangements to be made to protect the confidentiality of data, including confidentiality of information provided subject to legal limitations.

Except with your consent, we insure confidentiality of your identity and data throughout the conduction, reporting and publication of the research.

VI. Signature

I have read and understand the information in this form. Researchers have answered my questions and concerns and I have a copy of this consent form. Therefore I consent to take part in the research project.

Appendix E (i) (continued) Teachers' informed consent to participate in the study.

Teacher's signature:

____

Name in Block capitals

____

Signature of Researcher

____

Name in Block capitals

____

Date

____

Appendix E (ii) Students' consent form to participate in the study.

LETTER TO PARENTS (ON DCU HEADED PAPER)

Dear Parent or Guardian,

I wish to ask your permission to use surveys and test results that will be completed by your child at school in a study of teaching methods. Much of the science curriculum at Junior Certificate is taught using experiments as a basis for learning. This complements inquiry based learning that is also used in the classroom. It is intended to teach three sections of the course using inquiry-based learning.

As part of the study your child will fill out two questionnaires on his or her attitudes to science, one at the beginning and one at the end of the study period. He /she will sit a test before and after each section.

The identity of your child or his or her results will not be revealed to anyone. Their teacher will code the results before giving them to the researcher. No student will know who else is participating, as they will all sit the same tests. The only difference is that the non-participants' results will not be used in the study.

If you are happy for your child to participate, can you read the information provided and sign the consent form with your child? Please return the consent form to your child's teacher in the envelope provided. Indicate whether or not you wish the child to participate.

Yours faithfully,

Dr Katie Corbett

Appendix E (ii) (continued) Students' consent form to participate in the study.

8. PLAIN LANGUAGE STATEMENT *(Approx. 400 words – see Guidelines)*

Understanding and Enjoying Science Better

The purpose of this study is to improve students' enjoyment, understanding and ability to learn by inquiry.

Transition Year (TY) and first year students will be surveyed to find out how much they use information media such as computers, television, newspapers and libraries. These are the media where they would find out information without assistance from teachers or parents.

A survey will be carried out of media usage (Computers, TV, newspapers, books) by first and transition year (TY) students.

Junior Science topics will be taught through inquiry based learning (IBL) to find out who prefers to this form of learning based on experiment and class work. Next, the group will be surveyed to find out their attitudes to learning in general and inquiry in particular.

The TYs will develop a computer-based module for a Junior Certificate topic to be taught to first years. They will be tested on their knowledge and understanding of the topic before and after their research. This module developed by TYs will be taught to first years who will be tested on their knowledge, understanding and attitude to the topic. The results in both modules will be monitored.

Involvement in this study will benefit these students because there will be a heavy emphasis on their ability to understand the content. Their ICT skills will improve. They will also benefit as the will be made aware of a greater variety of learning styles that may eventually help them recognise their own favourite approach to learning.

Confidentiality

No students' results will be made available outside the study to their teachers and will not be recorded anywhere else. The students will not be identified while participating in the study or at the reporting stage.

All digital and hard copies will be disposed of by researchers within 12 months of completion and publication of project outcomes. All hard copies will be diposed of in the All Doc professionally shredded containers within DCU.

Right to withdraw

Involvement in this study is voluntary and withdrawal at any stage will be without penalty. That is, if the student withdraws, they will still participate fully in class but their tests will not be used as part of the study.

The school is aware that this study will take place over the coming year.

If the participants have concerns about this study and wish to contact an independent person, please contact: The Secretary, Dublin City University, University Research Ethics Committee, c/o Office of the Vice-President for Research, Dublin City University, Dublin 9. Tel: 01 7008000.

Appendix E (ii) (continued) Students' consent form to participate in the study.

9 INFORMED CONSENT FORM

9.1 Students

I. Research Study Title

Improvement of attitudes to science using inquiry based learning.
The research is being carried out by Dr Katie Corbett, a post -primary teacher at Skerries Community College and is being supervised by Dr Paul van Kampen and Dr James Lovatt at Dublin City University.

II. Clarification of the purpose of research.

This research relates to the evaluation of inquiry based learning (IBL) within the Junior Science syllabus. The study expects to improve students' conceptual understanding and ability to learn by inquiry. The investigators also which to assess the impact of inductive learning has on students' interest in science. If this method is successful, then other modules will be taught in this manner.
It is intended to publish the results in an education research journal. All names will be confidential.

III. Confirmation of particular requirements as highlighted in the plain language statement.

To the Student:
Please read the following questions and circle either Yes or No
Have you read or had read to you the Plain Language Statement? YES/ NO
Do you understand the information provided? YES/ NO
Have you had an opportunity to ask questions and discuss this study? YES/ NO
Have you received satisfactory answers to all your questions? YES/ NO
Are you aware that the discussions/ interviews may be audio-taped? YES/ NO

IV. Confirmation that involvement in the Research Study is voluntary.

Your involvement is entirely voluntary however; if you decide not to take part there is no disadvantage to you. Taking part is completely unrelated to any class assignments during the year. You can withdraw from the study at any time.

V. Advice as to the arrangements to be made to protect the confidentiality of data, including confidentiality of information provided subject to legal limitations.
Except with the consent of the participant or guardian, we insure confidentiality of the participant's identity and data throughout the conduction, reporting and publication of the research.

Appendix E (ii) (continued) Students' consent form to participate in the study.

VI. Signature

I have read and understand the information in this form. Researchers have answered my questions and concerns and I have a copy of this consent form. Therefore I consent to take part in the research project.

Participant's signature:

____

Name in Block capitals ________________________________

Signature of Parent /Guardian ________________________________

Name in Block capitals ________________________________

Signature of Researcher ________________________________

Name in Block capitals ________________________________

Date ________________________________