Influencing Pre-Service Science Teachers' Approach to Inquiry and Assessment

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Declaration

I hereby certify that this material, which I now submit for assessment on the programme of study leading to the award of Doctor of Philosophy is entirely my own work, and 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.

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Date:

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A little education is no weight to carry

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Wit beyond measure is man's greatest treasure

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Glossary

Notation	Meaning
BE	Beginner with inquiry
ESTABLISH	European Science and Technology in Action: Building Links with Industry, Schools and Home
IBSE	Inquiry based science education
IBSEA	Inquiry based science education and assessment
Lab	Laboratory
MDS	Multi-dimensional Scaling
NB	Notebook
NE	No experience with inquiry
PL	Post lab
PST	Pre-service teacher
PSTW	Pre-service teacher with teaching experience
PSTWO	Pre-service teacher without teaching experience
SAILS	Strategies for Assessment of Inquiry Learning in Science
SE	Some experience with inquiry
T	Test
TA	Teaching approach
TEP	Teacher education programme
VE	Very experienced with inquiry

Abstract

Influencing Pre-Service Science Teachers' Approach to Inquiry and Assessment

– Leeanne Hinch

Inquiry based science education has been identified in the literature as a methodology suitable for the development of content knowledge and skills in science. Over the past number of years, inquiry teaching and learning has been endorsed as an appropriate method for learning science in various reports and now has a place in many national curricula. However, research has shown that there are many challenges faced by teachers who are attempting to implement inquiry instruction in their classrooms. A particular challenge faced by pre-service teachers is that, in spite of the content of initial teacher education programmes, novice teachers frequently teach as they were taught themselves in the classroom. During initial teacher education, pre-service teachers need to be prepared in such a way that they are confident and competent with inquiry instruction

This study focusses on the determination of European and Irish pre-service teachers' understanding and views of inquiry practices, and of assessment in inquiry practices, and how these change following participation in inquiry workshops. This study determined that the greater the pre-service teachers' understanding of inquiry, the more they would consider inquiry as their main teaching method in future. Prior experience with inquiry has an impact on pre-service teachers' understanding and views towards inquiry. European pre-service science teachers' inquiry assessment practices and their confidence with carrying these out in the classroom have also been investigated. Confidence had a major impact on the practices of the pre-service teachers.

These findings were then used to design a chemistry laboratory module for pre-service teachers to support them in the development of their knowledge of and views towards inquiry. The laboratory based chemistry module was developed and implemented with a group of pre-service teachers. Evaluation of the impact of the module shows that participants' inquiry skills were successfully developed and there is a movement towards teaching through inquiry practices. Key aspects of the module are highlighted to inform other such programmes.

Introduction

Providing quality STEM education at all levels is important for the innovative and economic ambitions of a society. Excellent pre-service teacher education is of critical importance for the promotion of STEM and the quality and quantity of future STEM graduates. Inquiry based science education (IBSE) has been shown to be an effective pedagogy for teaching science with improved conceptual understandings (Lloyd & Contreras, 1987), cognitive achievement (Shymansky, et al., 1983; Wise & Okey, 1983) and content knowledge gains in students (Von Secker, 2010; Qureshi, et al., 2016) over more traditional methods that focus on content transmission. Shymansky et al. (1983) also found that the scientific process skills of participating students improved following inquiry based learning initiatives while improved scientific reasoning and critical thinking skills have also been noted (Wilson, et al., 2010; Narode, et al., 1987). Additionally, students' overall attitudes towards science have been shown to become more positive after they have taken part in inquiry based learning (Shymansky, et al., 1983; Chang & Mao, 1999).

Over the past number of years, inquiry teaching and learning has been endorsed as an appropriate method for learning science in various reports and now has a place in many national curricula (NCCA, 2015; Ontario Ministry of Education, 2008; NRC, 2000). However, research has shown that there are many challenges faced by teachers who are attempting to implement inquiry instruction in their classrooms. These challenges or barriers need to be overcome so that inquiry learning may be facilitated effectively.

Implementing inquiry successfully in the classroom is not simply about possessing the correct curriculum materials. The teacher must possess a positive attitude towards inquiry, where they believe both in the value of the inquiry process and of allowing students to have at least some control over what they are doing (Colburn, 2000). One of the main challenges faced by teachers in inquiry instruction is their lack of understanding of inquiry and lack of implementation strategies. Without an understanding of how inquiry works and what the role of the students and teachers are in the classroom, then it is unlikely that inquiry will be conducted effectively (Crawford, 2000; Roehrig & Luft, 2004; Hong & Vargas, 2016; ESTABLISH, 2014).

Teachers often believe that inquiry takes up too much time and as a result may struggle to cover the curriculum due to their already packed teaching load. Good inquiry lessons require planning prior to the class, and often involve a lot of practical work, which may seem like too time consuming for the teachers (Hammer, 1997; Anderson, 2007; Lehman, George, Buchanan, & Rush, 2006; Jackson & Boboc, 2008). Concerns about managing the inquiry class such as safety issues, materials needed and facilities required by the inquiry, unequal distribution of work during group work, getting students' attention, and providing makeup work for those students who have missed an inquiry-based activity have also been highlighted (Jackson & Boboc, 2008).

Various different inquiry programmes have been implemented with pre-service or in-service teachers (Michalow, 2015; Wee, et al., 2007; Luft, 2001; Lotter, et al., 2007). An aspect that is not typically covered in these programmes is guidance on how to assess the outcomes of inquiry lessons. This may be due to the fact that despite the emphasis on inquiry over recent decades, effective methods for assessing the skills used and developed during inquiry in large scale or high stakes settings remain elusive. The two approaches most commonly discussed are short answer tests for specific inquiry skills (Alonzo & Aschbacher, 2004) and hands-on performance assessments (Ruiz-Primo & Shavelson, 1996).

Changing teachers' assessment practices so that they are more appropriate for inquiry comes with its own challenges. Teachers need support if they are to change to inquiry based teaching. In light of this, this study aims to determine the impact of inquiry and inquiry assessment teacher education programmes (TEP) on pre-service science teachers, so that the approach adopted within these programmes whereby the participants experience inquiry first hand can be mainstreamed into a module within initial teacher education.

The overall question for this study is "What is the influence of focussed teacher education programmes on pre-service science teachers' (PST) inquiry and assessment approaches?"

This has been divided into three phases and each of these is dealt with sequentially, as follows:

1. Determination of PSTs' understanding and views of inquiry practices, and how these change following an inquiry teacher education programme.

2. Determination of PSTs' understanding and views of assessment in inquiry practices, and how these change following incorporation of assessment within an inquiry TEP.

Informed by the answers to phases 1 and 2 above,

3. How can PSTs be supported in the development of their knowledge and views of inquiry in an undergraduate chemistry laboratory module?

The first phase investigates the understanding and views of inquiry of pre-service teachers who participated in inquiry professional development programmes across Europe, within the framework of the ESTABLISH project (2014). The aim of this phase was to determine pre-service teachers' understandings of, and attitudes towards inquiry, as well as the challenges that they identify to inquiry instruction. Additionally, this phase aimed to determine the changes in these aspects following a series of focussed workshops in inquiry.

The second phase investigates PSTs' understanding of assessment in inquiry and how this assessment strategy links to their understanding of inquiry. This phase was carried out within the framework of the SAILS project (2016) and is informed by data from over 260 PST across Europe. This study also examines the change in their understanding and views of assessment following focussed inquiry workshops.

Informed by the results from the first two phases, and the literature in teacher professional development, particularly within the area of inquiry, a laboratory based chemistry module was developed in an effort to support the PSTs' development of positive attitudes and understanding of inquiry pedagogy. The module focussed on teaching general topics in chemistry through laboratory work which incorporated inquiry as well as other activities so the participants both experienced learning through inquiry as well as learning about inquiry. This provided the scope for modelling and evaluating the impact of varied lab work and assessments on learning within a pre-service teachers' educational programme.

This thesis consists of seven chapters. In Chapter One, the literature regarding several aspects of inquiry based science education is discussed; firstly, what is IBSE in relation to other forms of active learning, how it is carried out, its benefits and challenges are discussed. Secondly, what are the implications of IBSE for assessment, how is inquiry assessed, and what prevents teachers from changing their assessment practices. As the research question 3 above, will address the supports required for PST to develop their expertise in IBSE, then the third section of the literature review examines professional development programmes and identifies that aspects of these programmes made them successful. Much of this discussion is based on professional development programmes for in-service teachers as there is little information available for pre-service teachers. Finally, research on specific teacher education programmes in IBSE is discussed in terms of what was included in their approach, and how these programmes were evaluated. Chapter Two provides an overview of the research methodology, including the research objectives, the choice of methodology used, development of the evaluation tools in the form of questionnaires for specific phases of the study, and explanations of the statistical tests employed over the three main phases of the study.

Chapter Three reports on phase 1 of the study, determines the understanding and views of PST towards inquiry and the impacts of focussed workshops on these understandings and views. Chapter Four focusses on the results of phase 2, determining the PSTs' understanding of assessment in inquiry and how this links to their understanding of inquiry, and how focussed inquiry programmes impacts on this understanding. Informed by these results, Chapter Five discusses the development of a chemistry module for PST which will not only involves teaching chemistry but also introduces the PST to inquiry and assessment practices. Chapter 7 presents the main findings of the study and its implications for future development and integration of inquiry programmes within pre-service teacher education.

Chapter 1 - Inquiry, Assessment and Teacher Education

Over the past number of decades, inquiry based science education has been suggested as a suitable method for teaching science to students effectively. To aid in the adoption of this method in classrooms, it is necessary to prepare pre-service teachers (PST) as fully as possible for the task of teaching through inquiry. Teachers have control over the methodology that they use within their classrooms, however they do not have control over the curriculum or students' summative assessment. Many different views of inquiry education exist and many teachers may not be familiar with the process of teaching through inquiry. Therefore it is important initially in the context of this work to place inquiry based science education (IBSE) within the context of active learning pedagogies and to discuss the literature on IBSE within this context. This chapter presents literature on the area of inquiry based education, assessment, teacher education programmes, and inquiry specific teacher education programmes. It is divided into three main sections. In the first section, the various views of inquiry based science education and how it is evident in the classroom are discussed (Section 1.1). This is informed by research on the benefits of inquiry based instruction and the criticisms of the approach, including barriers to its implementation in the classroom.

The second section of this review discusses the area of assessment and how it is evident within the context of an IBSE approach (Section 1.2). How teachers are currently assessing and the barriers that they have to implementing particular types of assessments are discussed.

The final sections discuss literature on teacher professional development (PD), best practices in PD programmes that can influence teacher change and how these have been evaluated. An overview of why teacher reform often fails is also provided. This is considered for both in-service and initial (pre-service) teachers (Section 1.3). Additionally, successful inquiry professional development programmes and the aspects included within these approaches are also discussed (Section 1.4). While most of the literature relates to in-service professional development programmes, these have been included as the most effective messages may also be relevant to pre-service programmes.

1.1 Active Learning

Active learning is a term used to describe all the pedagogies which place the focus in the classroom on student activity and student engagement in the learning process (Roehl, et al., 2013). Authentic learning, problem-based learning, and inquiry learning are three popular active learning approaches. The first section of this chapter will focus predominantly on inquiry, but an overview of authentic learning and problem-based learning will be provided so as to highlight why inquiry was the approach focussed on within this study.

Colburn has stated that "*perhaps the most confusing thing about inquiry is its definition*" (2000). This confusion stems from the fact that inquiry can refer to at least three actions: what scientists do (e.g. conducting investigations using scientific methods), the pedagogy of how students learn or what students do (e.g. actively inquiring by thinking about a phenomenon or problem or by doing investigations into these problems) (Minner, et al., 2010). Different groups, communities, and government bodies depending on their preferences use these different meanings. In this work, inquiry is used in the context of how students learn and what students do.

When considering inquiry based science education (IBSE) as a pedagogical method, it is an approach to teaching and learning science that is conducted through the process of inquiry whereby the students are involved in the process of their learning. By being involved in the learning, students are constructing their own knowledge based on their first-hand experiences. This means that the students are not simply the recipients of information that is being dictated to them. This involvement affords the student a greater opportunity to think about and understand the new material. This method has been described as a problem-solving technique where the emphasis is placed on the investigation of the problem, as opposed to achieving the "correct" solution of that problem (Moore, 2009).

In 1996, the National Research Council released a report, "National Science Education Standards", recommending the use of inquiry instruction for teachers in the US. Within this report they asserted that inquiry is central to science learning and they described it as:

"*Scientific inquiry refers to the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Inquiry also refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study. Inquiry is a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results. Inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations. Students will engage in selected aspects of inquiry as they learn the scientific way of knowing the natural world, but they also should develop the capacity to conduct complete inquiries*" (NRC , 1996, p. 23).

Linn, Davis and Bell (Linn, et al., 2004) hold a similar idea of inquiry. They have essentially summarised the NRC's definition as they state that inquiry is the students' "*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*".

Some of the key characteristics of inquiry based learning are:

- "*Engagement with a complex problem or scenario, that is sufficiently open-ended to allow a variety of responses or solutions;*
- *Students direct the lines of inquiry and the methods employed;*
- *The inquiry requires students to draw on existing knowledge and identify their required learning needs;*
- *Tasks stimulate curiosity in the students, encouraging them to actively explore and seek out new evidence;*
- *Responsibility falls to the student for analysing and presenting that evidence in appropriate ways and in support of their own response to the problem*" (Kahn & O'Rourke, 2005)

When comparing inquiry to other active learning approaches, there are clear similarities with authentic learning. Authentic learning is based on the premise that abstract knowledge which is being taught in schools is not easily retrieved within everyday life by students within problem-solving contexts. It is suggested that when learning is separated from the contexts in which it is applicable, the knowledge can be seen by the learners as merely the outcome of education rather than that which can be used to help them solve problems. Authentic learning occurs in learning environments that:

1. *"Provide authentic contexts that reflect the way the knowledge will be used in real life;*
2. *Provide authentic activities;*
3. *Provide access to expert performances and the modelling of processes;*
4. *Provide multiple roles and perspectives;*
5. *Support collaborative construction of knowledge;*
6. *Promote reflection to enable abstractions to be formed;*
7. *Promote articulation to enable tacit knowledge to be made explicit;*
8. *Provide coaching and scaffolding by the teacher at critical times;*
9. *Provide for authentic assessment of learning within the tasks"* (Harrington & Oliver, 2000)

As such, authentic learning contains many of the same characteristics as an inquiry based approach, except that the learning is more situated within a particular context in an authentic learning environment. The emphasis is on real life contexts in collaborative learning environments. As such, IBSE can be considered as authentic learning provided the context is real life, and that it provides a broad range of possible outputs.

Problem-based learning is a type of inquiry learning which originated within the fields of medicine and engineering where solving problems is an important aspect (Lee, 2012). Problem-based learning is focussed on students tackling an ill-structured problem with the teacher being a facilitator of the learning and the learners involved in self-directed learning. "Ill-structured" problems are open-ended problems that have multiple solutions and this is the driving force behind the students' inquiry (Savery, 2015). Although inquiry (IBSE) can also involve open-ended problems, it also provides the scope for scaffolding the students throughout their investigations by focussing on specific aspects at a time, not just the solving of the problem.

In light of these descriptions, the view that the researcher takes of inquiry is that a lesson typically focusses on a question that can be investigated. The question may be posed by the teacher or the learner, but students must have something to investigate. They should have some control over the process of obtaining an answer. This may involve answering more questions as part of the process to eventually arrive at a plausible solution or conclusion to the original question. However, inquiry isn't just about *asking* questions. The inquiry process is something deeper. Students should question into something and dig further into an area to discover something that they did not see or understand before. Gordon (2004) has considered inquiry as a "systematic search for knowledge and truth" and as part of inquiry learning, the learner must engage with the problem and attempt to answer the questions that may arise. When there is a question that the students must themselves find an answer to, they take greater control over the direction of the learning, which makes the learning more open-ended.

Within the task of answering a question, students must learn the skills to design, interpret, and evaluate their work. Students are given the opportunity to come up with their question, research the problem, discuss their findings, and reflect on next steps to finding solutions. This affords the students the opportunity to meet with unexpected results that they must learn how to deal with and explain.

An appropriate description of inquiry which covers these aspects was generated by Harlen and Allende (2006). They believe students should be:

- "*engaged in observation and, where possible, handling and manipulating real objects;*
- *pursuing questions which they have identified as their own even if introduced by the teacher;*
- *taking part in planning investigations with appropriate controls to answer specific questions;*

- *using and developing skills of gathering data directly by observation or measurement and by using secondary sources;*
- *using and developing skills of organising and interpreting data, reasoning, proposing explanations, making predictions based on what they think or find out;*
- *working collaboratively with others, communicating their own ideas and considering others' ideas;*
- *expressing themselves using appropriate scientific terms and representations in writing and talk;*
- *engaging in lively public discussions in defence of their work and explanations;*
- *applying their learning in real-life contexts*;
- *reflecting self-critically about the processes and outcomes of their inquiries."*

1.1.1 Teachers in the Inquiry Classroom

What primarily distinguishes inquiry instruction from more traditional methods is the distinct role that the teachers play in the inquiry classroom. The role of the teacher and the role of the student are flipped from the roles they would traditionally play in the classroom. In the student-centred learning environment of the inquiry classroom, the teacher facilitates the learning, rather than dictating it. Teachers move away from outcome-based education towards that which is more process-based.

Ash and Kluger-Bell (2000) compiled a list of "inquiry indicators" that highlight the special characteristics of what students and teachers do. They believe that in the inquiry classroom, teachers:

- "*Model behaviours and skills by guiding their students and showing them how to use new tools/ materials/ skills, etc;*
- *Support content learning;*
- *Use multiple means of assessment;*
- *Act as facilitators of learning*";

And following from that, in the inquiry classroom, students:

- "*View themselves as active participants in the process of learning;*
- *Accept an "invitation to learn!" And readily engage in the exploration process;*

- *Plan and carry out investigations;*
- *Communicate using a variety of methods;*
- *Propose explanations and solutions and build a store of concepts;*
- *Raise questions;*
- *Use observations;*
- *Critique their science practices*" (Ash & Kluger-Bell, 2000).

Banchi and Bell (2008) see inquiry as being on a continuum that is subdivided into four levels. Some teachers may believe that their students must be designing and conducting every aspect of scientific investigations for it to be considered an inquiry activity, but Banchi and Bell state that this is simply not the case. Students cannot be expected to have the capabilities and skills to design and carry out their own investigations instantly or without any practice. The four levels they have put forward provide different amounts of guidance to the students, and this allows the students to develop and progress towards deeper scientific thinking (Table 1.1). The amount of information provided to the students varies depending on the inquiry level, from both question and procedure provided in a confirmation inquiry task to an open inquiry task where students generate their own question and design their own procedures.

Table 1.1: The four levels of inquiry and the information given to the student in each one.

Inquiry Level	Guiding Question	Procedure	Solution
1. **Confirmation Inquiry –** Students confirm a principle with an activity when the results are already known	**Given**	**Given**	**Pre-determined**
2. **Structured Inquiry** – Students investigate a question provided by the teacher using a given procedure	**Given**	**Given**	**Not pre-determined**
3. **Guided Inquiry –** Students investigate a question provided by the teacher by designing or selecting their own procedure	**Given**	**Not given**	**Not pre-determined**
4. **Open Inquiry -** Students investigate questions that are students generated and design or select their own procedure	**Not given**	**Not given**	**Not pre-determined**

From Banchi & Bell, 2008

Jarrett has also described inquiry instruction as being on a continuum (Figure 1.1), and how a teacher may progress from using structured inquiry initially to using open inquiry (1997). This continuum demonstrates six different levels, increasing in sophistication from textbook activities up to completely open-ended activities.

Banchi and Bell's four steps map onto this progression to open inquiry, but Jarrett includes two additional steps at the beginning which incorporate textbook activities and teacher demonstrations. This highlights the scaffolding that is necessary to move students towards learner independence. It is difficult for students to tackle open-ended inquiry without preparation, so a scaffolded structure allows students to build up to more control and self-direction.

In my opinion, the idea of scaffolding is very important as students cannot carry out open inquiry activities successfully without having first developed the skills necessary to do so through other more guided or structured activities. The nature of these activities carried out from textbooks, demonstrations and "cookbook" experiments needs to be focussed towards inquiry and developing inquiry process skills of questioning, justification of results, variation in investigation procedures, etc., otherwise these are not useful scaffolds. For example, a cookbook experiment could be used in an inquiry way if students were given slightly different procedures which resulted in a variation in results. Discussing these results and examining the quality of these results would enable students to develop useful inquiry skills.

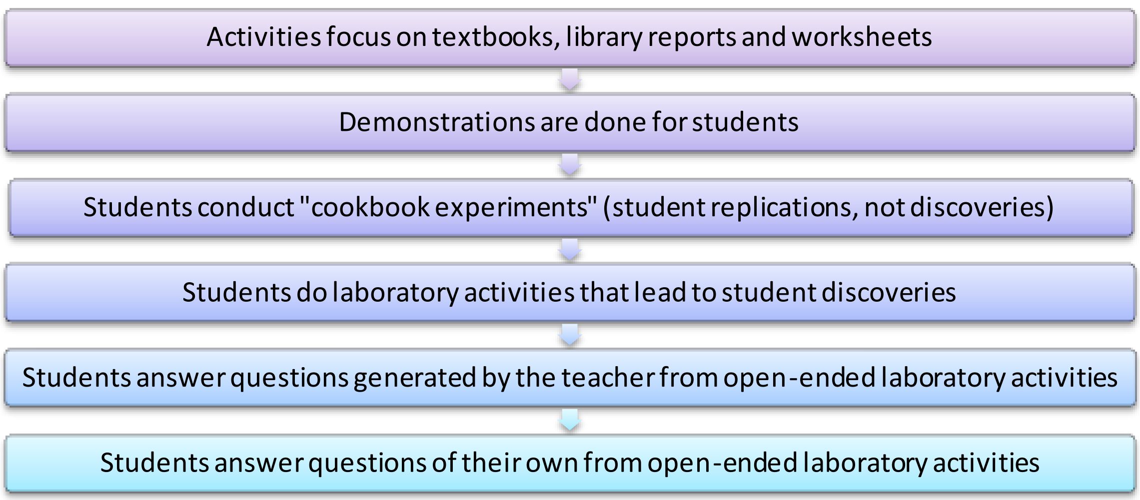


Figure 1.1: Summary of Steps toward Using Open Inquiry
Adapted from Jarrett, 1997

In Table 1.2, variations in instruction relative to different aspects of inquiry are given. The direction given by the student and teacher are indicated on the bottom of the table. For each of the five essential features of inquiry (as stated by the NRC) as you move toward the right of the table the teacher has more input into the direction of the learning in the class with the consequence of less self-direction on the part of the student. Conversely, on the left side of the table the student has more input into the direction of their own learning, with the teacher supporting but not dictating the direction.

Table 1.2: Essential features of inquiry and variations in instruction

	Essential Feature	Variations			
1.	Learner engages in scientifically oriented questions	Learner poses a question	Learner selects among questions, poses new questions	Learner sharpens or clarifies question provided by teacher, materials, or other source	Learner engages in question provided by teacher, materials, or other source
2.	Learner gives priority to **evidence** in responding to questions	Learner determines what constitutes evidence and collects it	Learner directed to collect certain data	Learner given data and asked to analyze	Learner given data and told how to analyze
3.	Learner formulate **explanations** from evidence	Learner formulates explanation after summarizing evidence	Learner guided in process of formulating explanations from evidence	Learner given possible ways to use evidence to formulate explanation	Learner provided with evidence
4.	Learner connects explanations to scientific knowledge	Learner independently examines other resources and forms the links to explanations	Learner directed toward areas and sources of scientific knowledge	Learner given possible connections	
5.	Learner communicates and justifies explanations	Learner forms reasonable and logical argument to communicate explanations	Learner coached in development of communication	Learner provided broad guidelines to use sharpen communication	Learner given steps and procedures for communication
	More ---------Amount of Learner Self-Direction --------- Less **Less --------- Amount of Direction from Teacher or Material ------ More**				

From NRC, 2000

A further gradation of student and teacher direction is depicted in Table 1.3 by Wenning (2005), showing that control of the learning moves from the teacher to the student between "Discovery Learning" and "Hypothetical Inquiry". In addition, the intellectual sophistication that the students require increases going from left to right across the table. Intellectual sophistication increases as the level of student interaction or inquiry increases, e.g. hypothetical inquiry involves students carrying out abstract thinking exercises whereas in discovery learning the teacher decides on the question to be examined and the sources to find the answer.

Table 1.3: Table of intellectual sophistication required by students in inquiry

Discovery Learning	Interactive Demonstration	Inquiry Lesson	Inquiry Lab	Real-world Applications	Hypothetical Inquiry
Low		**Intellectual Sophistication**			**High**
Teacher		**Locus of Control**			**Student**

From Wenning, 2005

These different variations in inquiry are often referred to as structured inquiry, guided inquiry, and open inquiry. In structured inquiry, the teacher provides the student with everything required to complete the experiment or task, including the procedure, but does not give the student information about the outcomes of the experiment. The idea is that students should discover relationships and analyse their data for themselves. In guided inquiry, the students are typically provided with the basic materials required to complete the task, but they must generate their own approach or procedure for solving the problem. In open inquiry, there is even less teacher direction. Often in open inquiry, the students generate their own problem to investigate, as well as determining the procedure and outcomes are unknown initially (Colburn, 2000).

1.1.2 Inquiry and the Learning Cycle

Learning cycles refer to an instructional model based on ideas of how students learn. Lessons conducted via the learning cycle promote active learning and as such are an application of the inquiry approach to learning. These instructional models can help teachers to plan and conduct inquiry lessons within their classrooms.

An early learning cycle instructional model developed for science was suggested by Atkin and Karplus (1962), referred to as "Guided Discovery", and was based on the work of Jean Piaget. This three step model encourages students to develop their own new reasoning patterns of a scientific concept as a result of their interaction with the phenomena in question and interactions with others. The steps involved in this learning cycle are summarised in Table 1.4. The student begins with exploring new material, the teacher then introduces some new knowledge to the student, and finally the student determines some new application for the knowledge or skill that they have just learned.

Table 1.4: Guided Discovery Learning Cycle

Exploration	Children explore new materials and/or ideas with minimal guidance or expectations of a specific achievement
Invention	Teacher defines a new concept or explain a new procedure in order to expand the pupils' knowledge, skills, or reasoning
Discovery	Children discern new applications for the concept or skill they have learned recently

Adapted from Atkin & Karplus, 1962

One of the most commonly used recent models is the 5E model developed by Bybee (2006). It emphasises students' prior knowledge, and how that can be used to further students' learning as part of the inquiry process. The five steps in the model are summarised in Table 1.5 and the cycle is illustrated in Figure 1.2.

As is evident from Figure 1.2, the students and teacher are evaluating the learning throughout the whole process. This can provide a form of assessment of what students now know and what they can do.

Recently a review was conducted by Pedaste, et al. on variations of inquiry understandings and the inquiry cycle (Pedaste, et al., 2015). Thirty two separate articles that described inquiry phases or whole inquiry cycles were included in the review. Many of the definitions used were quite similar or included much duplication. This overlap allowed the researchers to reduce the initial 109 terms for inquiry down to a more manageable 34 terms. These 34 terms were further rationalised into bigger groups, and following this reduction process they identified five distinct inquiry phases.

Table 1.5: 5E Learning Cycle

Engagement	The teacher assesses the learners' prior knowledge and helps them become engaged in a new concept through the use of short activities that promote curiosity and elicit prior knowledge
Exploration	Learners may complete lab activities that help them use prior knowledge to generate new ideas, explore questions and possibilities, and design and conduct a preliminary investigation.
Explanation	Provides opportunities to demonstrate their conceptual understanding, process skills, or behaviours. Learners explain their understanding of the concept.
Elaboration	Teachers challenge and extend students' conceptual understanding and skills. Students apply their understanding of the concept by conducting additional activities.
Evaluation	The evaluation phase encourages students to assess their understanding and abilities and provides opportunities for teachers to evaluate student progress toward achieving the educational objectives

* Adapted from Bybee, 2006

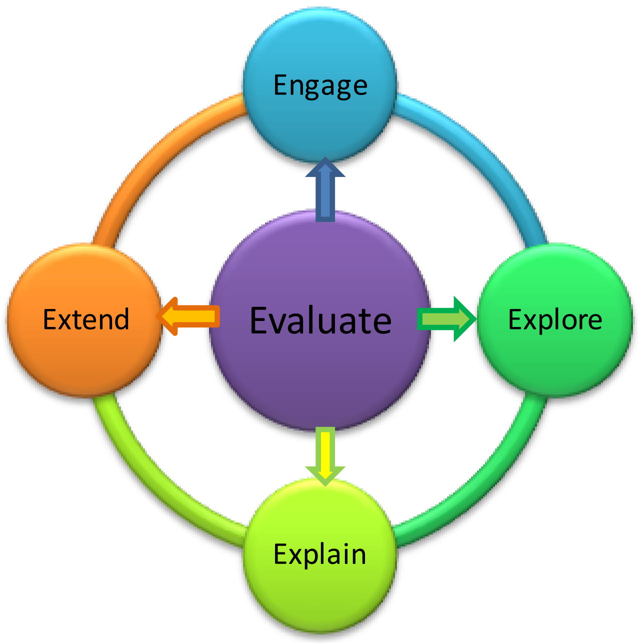


Figure 1.2: Summary of steps in 5E Learning Cycle
Adapted from Bybee, 2006

They determined that inquiry can be summarised into five phases - orientation, conceptualisation, investigation, conclusion and discussion, with some of these phases containing sub phases. Table 1.6 provides details of the phases.

A framework was developed which allows description of an inquiry cycle where all phases (and sub-phases) are present. Figure 1.3 highlights the various pathways that can be taken by teachers and students through an inquiry cycle. Three possible inquiry cycles that could be carried out can be observed by following the arrows in Figure 1.3:

(a) Orientation – Questioning – Exploration – Data Interpretation (possibility in the cycle to go back to Questioning) – Conclusion;

(b) Orientation – Hypothesis Generation – Experimentation – Data Interpretation (possibility in the cycle to go back to Hypothesis Generation) – Conclusion;

(c) Orientation – Questioning – Hypothesis Generation – Experimentation – Data Interpretation (possibility in the cycle to go back to Questioning or Hypothesis Generation) – Conclusion. (Pedaste, et al., 2015).

Table 1.6: Phases and sub-phases on the synthesised inquiry-based learning framework

General phases	Definition	Sub-phases	Definition
Orientation	The process of stimulating curiosity about a topic and addressing a learning challenge through a problem statement		
Conceptualization	The process of stating theory-based questions and/or hypotheses.	*Questioning*	The process of generating research questions based on the stated problem.
		Hypothesis Generation	The process of generating hypotheses regarding the stated problem.
Investigation	The process of planning exploration or experimentation, collecting and analysing data based on the experimental design or exploration.	*Exploration*	The process of systematic and planned data generation on the basis of a research question.
		Experimentation	The process of designing and conducting an experiment in order to test a hypothesis.
		Data Interpretation	The process of making meaning out of collected data and synthesizing new knowledge.
Conclusion	The process of drawing conclusions from the data. Comparing inferences made based on data with hypotheses or research questions.		
Discussion	The process of presenting findings of particular phases or the whole inquiry cycle by communicating with others and/or controlling the whole learning process or its phases by engaging in reflective activities.	*Communication*	The process of presenting outcomes of an inquiry phase or of the whole inquiry cycle to others (peers, teachers) and collecting feedback from them. Discussion with others.
		Reflection	The process of describing, critiquing, evaluating and discussing the whole inquiry cycle or a specific phase. Inner discussion.

From Pedaste, et al., 2015

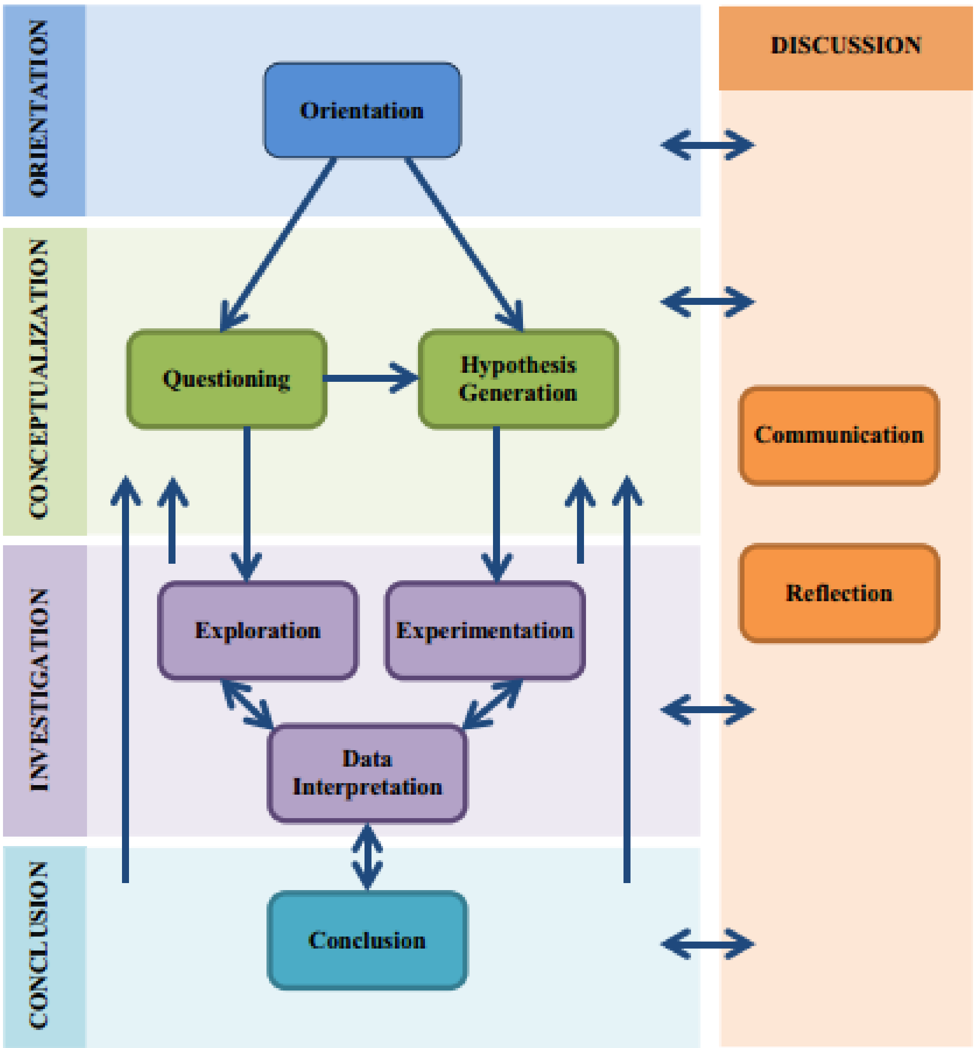


Figure 1.3: Inquiry-based learning framework (general phases, sub-phases, and their relations)
From Pedaste, et al., 2015

1.1.3 Benefits/ Criticisms of Inquiry Approach to Learning

Inquiry based learning provides students with an opportunity to develop their abilities to learn and think independently. During the past number of decades, numerous educators have suggested inquiry teaching as a method of enhancing learning in science. Much of the research on inquiry based science teaching and learning originated in the 1980's.

In a meta-analysis of science inquiry teaching research there were substantial effects on students' cognitive achievement, attitude to science and process skills following inquiry (Shymansky, et al., 1983). In another meta-analysis on the effects of various science teaching strategies on achievement, the effect size was also in favour of inquiry teaching for the cognitive outcomes of the students (Wise & Okey, 1983). Inquiry teaching has been shown to have positive effects on students' conceptual understanding (Lloyd & Contreras, 1987) and their critical thinking (Narode, et al., 1987). Due to the nature of the processes that the students are conducting during the inquiry lesson, they are more likely to develop a deeper understanding of the topic they are covering. Students need to think critically when they are making decisions and interpreting data during the lesson. This form of thinking allows the students to go beyond the surface knowledge that is typically achieved when students are more passive in the learning experience.

Further studies are quoted briefly in the next few paragraphs to highlight the range of topics covered and skills developed through inquiry education projects.

Von Secker (2010) has reported on the effects of a student-centred inquiry based model on excellence and equity in science. Excellence refers to the achievement of all students and equity is achievement among students from various demographic profiles. In his study involving 4,377 students, the use of inquiry was associated with higher science achievement in all students. When the teachers placed an emphasis on the five practices which constituted an inquiry approach, the average science achievement of all the students increased. With respect to the equity of achievement, the study found that inquiry based instruction was sensitive to social context and there was not equal achievement among students from advantaged and disadvantaged backgrounds. They determined that inquiry practices may in fact widen the gap among some groups of students whilst also narrowing the gap within others (Von Secker, 2010).

Other studies have shown the effects of inquiry instruction on science excellence and achievement. In a study involving approximately 1750 second level students, a forensic science module was taught through either guided inquiry or a traditional approach. It was found that students who were instructed by a guided inquiry approach achieved significantly higher post-test scores than those who received traditional instruction (Blanchard, et al., 2007).

In a Taiwanese study (Chang & Mao, 1999) comparing student outcomes from traditional instruction versus inquiry instruction in high school students, the effects on student learning and attitudes towards the subject matter were investigated. This study involved 612 ninth-grade students enrolled in 16 earth science classes. The students' learning was tested by looking at their knowledge, comprehension and application using 26 items; 5 items at the knowledge level, 16 items were at the comprehension level, and the remaining 5 were at the application level. When comparing the two methods of instruction it was determined that there was significantly higher achievement among the inquiry group students. These differences were due primarily to an increase in students' knowledge, not their higher order cognitive skills. The students' attitudes were examined by looking at their involvement, confidence and learning interest. Overall, the inquiry group had a significantly higher attitude score than those educated through traditional instruction. There was a significant difference in students' involvement and confidence, but not their learning interest. Overall, this study highlights the benefits of inquiry instruction on student attitude and achievement (Chang & Mao, 1999).

In a more recent study involving 58 students from 24 schools, participants completed a unit about sleep, sleep disorders and biological rhythms. Some of the students received inquiry based instruction, based on the 5E instructional model, whereas the rest were taught using more traditional methods. It was found that the inquiry students obtained significantly higher levels of achievement than their counterparts. Inquiry approaches were found to be more successful at developing the students' knowledge, scientific reasoning and argumentation (Wilson, et al., 2010).

The questioning practices of teachers who participated in an inquiry professional development programme were monitored pre- and post- programme. After the programme, teachers' use of questions aimed at getting students to voice their own ideas, opinions, experience and perceptions occurred twice as frequently. With an increase in these student-centred questions, students responded in a more articulate manner, with longer answers, and with a higher level of thinking. Additionally, it was found that the students wanted to conduct their own authentic investigations (Oliveira, 2010).

Educational reforms to promote inquiry-based science education are now ongoing in areas like Qatar and research is continuing on the benefits of this approach. A foundation chemistry course was developed where students in Qatar were instructed using Process Oriented Guided Inquiry Learning (POGIL) (Qureshi, et al., 2016). Quantitative data was obtained from content tests and open-ended student questionnaires. The results of this study are in line with many of the results discussed previously. Students instructed under the POGIL method self-reported an increase in their self-efficacy, interest, and a greater understanding of concepts. Additionally, this method resulted in improved mean scores on the content tests of the students with medium to large effect sizes (Qureshi, et al., 2016).

More recently, inquiry based learning has been promoted as a suitable method for learning science in various reports and curriculum documents (National Research Council, 2000; Minner, Levy, & Century, 2010; Rocard, et al., 2007; Ontario Ministry of Education, 2008; NCCA, 2015). However, in contrast several studies have been published which argue against the use of inquiry instruction. The use of inquiry learning has been rejected by Kirschner, Sweller and Clark (2006) in one such article. They believe that unguided or minimally guided instructional approaches, such as inquiry based learning, are less effective than guided instructional approaches. They postulate that these approaches are not as effectual because they overlook the structures that make up human cognitive architecture. These instructional methods continue without heed to the features of working memory, long-term memory, or their relationship, according to the authors. *"The major fallacy of [the inquiry-based] rationale is that it makes no distinction between the behaviours and methods of a researcher who is an expert practicing a profession and those students who are new to the discipline and who are, thus, essentially novices"* (Kirschner, et al., 2006).

A year later in 2007, Schmidt, et al. (2007) provided a commentary on Kirschner, et al.'s work. They agreed with the fact that minimally guided instruction may not be suitable for novices; however they disagreed that it is entirely ineffectual. Using the example of problem-based learning, they argue that with the flexible adaptation of guidance levels it can be compatible with our cognitive structures through scaffolding. Scaffolding students so that they can become independent learners is one of the aims of inquiry learning (Schmidt, et al., 2007). Mayer (2004) also argued for a more guided approach over a completely open environment. His work reviewed three historical attempts to promote constructivist learning using discovery teaching methods: discovery of problem-solving rules primarily from the 1960's, discovery of conservation strategies which reached its peak in the 1970's, and discovery of computer programming concept which peaked in the 1980's. Having compared guided discovery with pure discovery methods from these areas of literature, he concluded that guided discovery is more effective for students than pure discovery learning, such as open inquiry (Mayer, 2004).

Another criticism found in the literature refers to the scope or capacity of what can be done in a school. Rahm et al. (2003), have suggested that the major differences between the work that scientists do and the work that teachers do are too great for replicating the methods used by scientists in the classroom. They believe that science that students are capable of doing "*will always be different from what real scientists do"* (2003, p. 739). These differences are recognised in the literature, with Minner et al. (2010) defining what students do, what scientists do, and inquiry as a pedagogy, as distinct aspects that the word "inquiry" can refer to.

These criticisms are important as they highlight areas that should be considered when conducting inquiry in the classroom. However, they should not wholly restrict the teacher's vision for what their students can achieve. Completely open inquiry may not be suitable for novice students, but a teacher can get to a point where students are comfortable with working by themselves with less guidance over time. Although classrooms may never entirely replicate the working conditions of a scientist, this should not diminish the fact that when completely engaged in an inquiry activity, students can model and assume the role of scientist and excel in the task. Crawford has reported on one such classroom where students developed the capabilities to work in this fashion (Crawford, 2000).

Despite the general agreement about the benefits of inquiry instruction, many teachers do not use it frequently, or at all. Implementing inquiry successfully in the classroom is not simply about possessing the correct curriculum materials. The teacher must possess a positive attitude towards inquiry where they believe in the value of the process and of students having some control over what they are doing (Colburn, 2000).

Teachers have reported some barriers that need to be overcome so that inquiry learning may be implemented effectively. Anderson (2002) categorised the potential barriers that teachers may face to implementing inquiry teaching into three categories. Barriers can be grouped into (a) political dilemmas (such as resistance from parents or conflicts with teachers), (b) cultural dilemmas (various beliefs or values about teaching and assessment) and (c) technical dilemmas (the teachers' limited abilities when it comes to teaching and assessment) (Anderson, 2002).

Looking at cultural dilemmas, teachers need the correct mindset. They have to believe in the process of inquiry and believe that a method of teaching where the students construct their own knowledge is valuable. The Teaching and Learning International Survey (TALIS) is a group which aims to make the teaching profession more effective using policy development. TALIS surveyed teachers from OECD countries during 2007 and 2008 about various aspects of their teaching, including their beliefs and practices. It should be noted that this study pre-dates major discussions in Ireland on inquiry practices within the national curriculum. For this discussion, the results of Irish teachers are compared to five other countries, namely Austria, Belgium, Denmark, Norway and Poland. The results of this study show teachers across these six countries indicated stronger endorsement for constructivist beliefs about teaching than direct transmission beliefs, however the Irish teachers hold weaker constructivist beliefs than their European counterparts, and stronger direct transmission beliefs. Additionally, when asked about their practices, the Irish teachers used more structuring practices (e.g. reviewing homework, checking work and understanding) and less student-orientated practices (e.g. allowing student co-determination of lesson content) and enhanced activities (e.g. assigning projects and the creation of products) than the other European teachers (Sheil, et al., 2009). There is evidently a particular issue here in Ireland with allowing students to direct their own learning.

It has recently been shown that within Ireland, second level school teachers are more resistant to constructivist teaching than primary school teachers, who are more open to it. This was determined using the CLES questionnaires which contain questions which provide insight into the degree that teachers' classroom practices might be considered constructivist (Gash & McCloughlin, 2010). This is important as current and future Irish second level school teachers are a major focus of this research.

Teachers' own lack of understanding of inquiry can be a barrier to implementation (Zion, et al., 2007; Laius, et al., 2009). As part of an inquiry professional development programme, it was also found that teachers were unconfident delving into areas of science they knew little about themselves. They further believed students' learning would be inhibited without their constant guidance and influence (Lotter, et al., 2007). This indicates a lack of confidence both in themselves and the approach itself. Similarly, Zion et al.'s study showed that participants' own lack of scientific knowledge was a barrier as the teachers felt that they could not facilitate their students in a topic that they were not proficient in (Zion, et al., 2007).

A technical dilemma that has been reported as a barrier over the past two decades is that due to the teaching loads that teachers must cover, some feel that they don't have the time for inquiry instruction (Hammer, 1997; Lehman, et al., 2006; Jackson & Boboc, 2008; Hong & Vargas, 2016). During inquiry training programmes, time was identified as a reason why participants would have difficulty with implementing inquiry in their classrooms (Zion, et al., 2007). Difficulties with completing already overloaded curricula using inquiry is often the reason reported by teachers why they don't carry out inquiry in their classrooms (Laius, et al., 2009). Interestingly, in this study, they found that the non-adopters of inquiry indicated that time and curriculum concerns were issues, whereas those who carried out inquiry did not cite these as obstacles.

Concerns about safety issues, materials needed and facilities required for inquiry, unequal distribution of work during group work, maintaining students' attention, and providing makeup work for those students who have missed an inquiry-based activity are all issues raised by teachers when considering inquiry instruction (Jackson & Boboc, 2008; Lehman, et al., 2006).

Established teachers may be uncomfortable changing from their traditional teaching methods, but pre-service and novice teachers also face their own, individual barriers to implementing inquiry instruction when they enter the classroom. Prospective teachers often don't feel confident enough to engage with their students in inquiry. They may not feel as if they have enough techniques and strategies to implement inquiry lessons effectively in their own classrooms (Crawford, 2007). Without the confidence to deal with some of the uncertainties associated with inquiry instruction or strategies to deal with this, pre-service and newly qualified teachers may not attempt inquiry, or may implement it unsuccessfully in their classrooms. An adequate grasp of content knowledge was found to play a key role in whether or not novice teachers implement inquiry successfully. Without a good standard of content knowledge, novice teachers will rely on textbooks (Roehrig & Luft, 2004).

Summary

The evidence detailed above consistently shows that when implemented correctly, inquiry based science has positive effects on students' knowledge, critical thinking, and attitudes towards science. Despite its positive impacts, it is not widely carried out, due to various barriers faced by teachers. Barriers such as teachers' views and understanding of inquiry, lack of content knowledge, and technical barriers such as time, and resources need to be addressed within teacher education programmes to enable teachers to carry out inquiry successfully.

In summary, the researcher takes the view that inquiry is a pedagogical approach to developing student thinking about all aspects of science. The definition of inquiry used within Chapters 3 and 4 is that by Linn, Davis and Bell (Linn, et al., 2004) which focusses on what the students are doing in the classroom.

The next section examines the assessment opportunities that are provided in an inquiry classroom.

1.2 Assessment in Inquiry

Inquiry processes in the classroom present many more opportunities for assessment over traditional activities; therefore the following section examines assessment methods and why changes in assessment practices are difficult. Teachers have reported that curriculum and time pressures are inhibitors to changing practice towards inquiry. These are presumably also factors which would impede assessment in inquiry. Therefore if further opportunities for assessment were available to teachers then perhaps these barriers would be reduced.

1.2.1 Methods of Assessment

If students are to develop their understanding of science and scientific skills through for example direct investigative experience, their own research, or discussions with peers, then teachers need to find evidence of students' existing understandings and skills so that they may identify the next steps in learning for the students. Using this information they could provide feedback and guide their students towards the goal. This is the role of formative assessment and as such, formative assessment should be embedded within inquiry teaching (Harlen, et al., 2003).

In a review of literature on feedback, the positive impact on students' learning was found to be substantial (Black & Wiliam, 1998). If teachers are aware of how their students are advancing, or if they are having difficulties with an area, they can use this information to adapt and adjust their teaching. This can be done by attempting alternative approaches or devoting more time to the area. Teachers can find out where the students are progressing or struggling in a variety of ways, including observation, written work, and classroom discussion. In a later essay included in the book "Everyday Assessment in the Science Classroom", Black (2003) highlights the issue that many teachers believe that they are engaged in formative assessment, when in fact they are not. This can happen when, even though they are listening to their students, they proceed with their lesson plan irrespective of what they have just heard (Black, 2003).

Despite the emphasis on inquiry over the past number of decades, effective summative assessment methods for assessing the skills used and developed during inquiry in large scale or high stakes settings remain elusive. There are two approaches which are commonly discussed for the summative assessment of inquiry and these are short answer tests for specific inquiry skills (Alonzo & Aschbacher, 2004) and hands-on performance assessments (Ruiz-Primo & Shavelson, 1996).

Short tests serve the purpose of assessing more cognitive aspects of inquiry such as whether they can develop a question that can guide a scientific investigation, decide how to answer that question and draw conclusions from their results. Short tests essentially assess inquiry in pieces. Assessing in this manner is less expensive and less time consuming than hands-on performance assessments, and does not unfairly impact students with little content knowledge. These factors mean that short answer tests can be integrated into large scale testing. However, some argue that hands-on demonstrations or performance assessments are more appropriate for assessing inquiry (Alonzo & Aschbacher, 2004). There is a disconnect between the complex science knowledge and skills that inquiry aims to develop and the science knowledge and skills that static, paper and pencil tests have the capacity to assess (Quellmalz, et al., 2009).

Performance assessments are considered more appropriate for assessing inquiry as particular skills are often required to solve problems. In the science classroom, performance assessment is a method of assessing students when they are provided with a problem to be solved and students must attempt to produce a solution using their skills and the laboratory equipment provided. Unfortunately, this method of assessment is not often used, or used poorly. In addition to the higher cost and time consuming nature of performance assessments, they are not often used in high stakes testing due to the difficulty in obtaining reliable assessments. A large amount of data is required for this form of assessment to be considered fair and reliable (Shavelson, et al., 1999). Inexpertly designed performance assessments do not test higher order thinking skills like they are intended to, and professional development is necessary to train teachers how to construct performance assessments properly (Ruiz-Primo & Shavelson, 1996).

In Harlen's (2013) recent book on the assessment of IBSE, she discusses the assessment of science inquiry skills and lists some important points about their assessment as follows:

- *"First, is the obvious one that students need to be involved in using the inquiry skills in order to assess what they do;*
- *Second, since the context and subject of the situation in which the skills are to be used affects the ability to use the skills, the task should be set in a familiar context if possible or several contexts should be used to reduce the sampling error;*
- *Third, as in the case of assessing understanding, the tasks should be authentic and engaging to the students."*

To assess in this manner, the task that the students are completing might involve:

- "*Carrying out in practice a complete inquiry to address a given question or problem providing opportunity for evidence to be collected about the use of a range of the skills;*
- *Producing a plan on paper for a complete inquiry to address a given question or problem;*
- *Considering a particular part of a given investigation, such as the variables that need to be manipulated or controlled, the evidence that needs to be collected, or the interpretation of some given data.*" (Harlen, 2013)

Research exploring how teachers assess student achievement in science in second level schools is relatively rare (Jakobsson, 2015), but indications are that teachers' assessment practices are at odds with inquiry appropriate assessment. Despite over 20 years of changes in the Swedish national curriculum which prescribe students' participation in assessment, teachers continue to use traditional assessment strategies and focus primarily on paper tests, with few teachers using performance-based assessments (Jakobsson, 2015). These assessments focus on the outcomes of learning, whereas in inquiry, the process of learning is also valuable.

1.2.2 Obstacles to Changing Assessment Practices

There are numerous reasons why teachers may not change or broaden their assessment practices. Teachers may misunderstand the purpose of assessment, they may not have the time to change or develop new assessment materials, or they may feel restricted by extrinsic issues such as high-stakes testing. It is important to understand these obstacles so that they can be addressed, where possible, in future teacher education programmes. The main obstacles identified shall be discussed within this section, under the following headings: (a) misunderstandings of assessment, (b) time for assessments, (c) assessment of group work, (d) high stakes testing and (e) understanding of assessment.

(a) Obstacles based on misunderstandings of assessment

Numerous different challenges have been highlighted throughout the literature that hinder teachers from assessing in particular ways, or changing assessment practices. Some obstacles that teachers face are rooted in tradition, which are often based on their opinions or misunderstandings. In a study by Guskey (2011) he discussed five such obstacles that prevent teachers from changing their grading practices, and the misunderstandings that have been responsible for their manifestation. He lists these as:

- "*Grades should provide the basis for differentiating students;*
- *Grade distributions should resemble a normal bell-shaped curve;*
- *Grades should be based on students' standing among classmates;*
- *Poor grades prompt students to try harder, and*
- *Students should receive one grade for each subject or course* (Guskey, 2011)."

Guskey (2011) stated that when teachers enter the profession they must decide whether they should select talent or develop it. If an educator's purpose is to only select talent, then they must work to maximise the differences between their students and create as much variation as possible in the students' scores. However, if a teacher wishes to develop talent then this is not how (s)he should assess. A teacher would do everything in their power to ensure that every student learns and, as a result, there would be minimal differences between the students' scores (Guskey, 2011). As the nature of teaching involves attempting to help students to attain particular learning goals, it is an intervention. If the distribution of students' results resemble a bell shaped curve, then the teaching, or intervention, has not succeeded. The idea that grades should be based on students' standing among classmates tells the teacher very little about the student. According to Guskey, "*in such a system, all students might have performed miserably, but some simply performed less miserably than others*" (2011). The fourth misconception was 'poor grades prompt students to try harder'. In this paper, Guskey says that no research is available that supports the notion that low grades encourage students to try harder. Finally, the idea that students should receive one grade for each subject or course is comparable to "*combining measures of height, weight, diet, and exercise into a single number or mark to represent a person's physical condition, we would consider it laughable*" (2011, p. 19). And yet, teachers combine various different factors to determine a students' grade.

These misconceptions about assessment relate primarily to summative assessment. Therefore a focus should be placed on highlighting the role and importance of formative assessment within the classroom.

(b) Obstacles based on Time

Another example of a barrier that teachers face in changing assessment practices was discussed in a study by Wolfe and Miller (1997). This paper identified a variety of obstacles that second level teachers admitted to facing when implementing portfolio based assessments. Teachers (206) from 16 American second level public and private schools took part in a trial of the American College Testing Portfolio System. This is a portfolio based system which allows teachers to use standard classroom work for assessment outside of the teachers' classroom. There were roughly equal numbers of science, mathematics and language arts teachers participating in this study. Before the field test, teachers completed a questionnaire that determined their attitudes about how serious they considered some of the barriers to implementing portfolio assessment. They responded on a scale of 1 to 4, with 1 being unlikely problem and 4 being a serious problem. The main results are shown in Table 1.7. They found that the most troublesome obstacles that teachers faced were the amount of time involved and the reporting or generating of scores. Time, with respect to assessment, does not just mean how long it takes a student to complete the assessment. Time refers to the planning time, the time to construct the assessment and the time to implement the assessment (Wolfe & Miller, 1997).

Table 1.7*: Potential Barriers to Portfolio Implementation*

Category	*Items*	*M*	*SD*	*n*
Time	Planning time, construction time, implementation time, release time	0.83	0.21	4
Scores	Scoring portfolios, scores to students, scores to parents, scoring rubrics, assigning grades, outside uses	0.49	0.18	6
Resources	Lack training, lack plan, education money, lack storage, lack materials, lack information	0.02	0.37	6
Instruction	Preparing portfolios, guiding instruction, curriculum changes, instructional changes, mandated curriculum, cover letters	–0.02	0.36	6
People	No benefits, student resistance, teacher resistance, parent resistance, lack group, lack motivation, coordinator resistance, administrator resistance	–0.78	0.69	8

From Wolfe & Miller, 1997

(c) Obstacles based on Assessment of Group Work

Garfield and Gal suggest that assessing the outcomes of group work is an area that teachers struggle with. Teachers are concerned about motivating all of the students to take part and contribute equally in group work, and also are concerned about the fairness of grading such work (Garfield & Gal, 1999).

When students within a group do not have equal motivation for the task then there is what is known as a "free-rider" problem. Free-riding within a group has been defined as: ''*the problem of the non-performing group member who reaps the benefits of the accomplishments of the remaining group members with little or no cost to him/herself''* (Morris & Hayes, 1997). Some studies have shown that within assessments where it is harder to identify "who did what" in a group task, then the likelihood of loafing or free-riding is more likely to occur (Davies, 2009). Appropriate assessments need to be used so that students recognise that they will be assessed fairly based on their contributions.

In a study by Cizek et al. (1996) where they looked at elementary school teachers' assessment practices, they found that several teachers wanted to assess cooperation and group work as something that might contribute to the students' grade. However, they found that it was often uncertain whether these were actually assessed in the methods used by the teachers (Cizek, et al., 1996).

(d) Obstacles related to High-Stakes Testing

The dangers of high-stakes testing have been articulated by Madaus (1999) when he stated:

"The long-term negative effects on curriculum, teaching, and learning of using measurement as the engine, or primary motivating power of the educational process, outweigh those positive benefits attributed to it. The tests can become the ferocious master of the educational process, not the compliant servant they should be. Measurement-driven instruction invariably leads to cramming; narrows the curriculum; concentrates attention on those skills most amenable to testing; constrains creativity and spontaneity of teachers and students; and finally demeans the professional judgement of teachers" (Madaus, 1999)

An American national study published in 2003 looked into the perceived effects of state-mandated testing programs on teaching and learning in various states (Pedulla, et al., 2003). Over 4000 teachers responded to the survey and were then separated into two groupings; the teachers were considered to be teaching in either a high-stake or low-stake testing environment. Some of the results of this study were discussed in a paper by Abrams, Pedulla, and Madaus (Abrams, et al., 2003). Within that paper, they discussed how the research determined that 76% of high-stakes teachers and 63% of low stakes teachers said that the testing programmes implemented in their state had lead them to teach their students in ways that contradicted their own ideas of what sound educational practice was. Not only was the teaching affected by high stakes testing, but their assessment practices were as well. Table 1.8 shows the percentage agreement with statements based on stake level. 51% of teachers in high-stakes states reported that they created their classroom tests so that they are in the same format as the state-mandated test. This was in comparison to only 29% of teachers in low-stakes states who admitted to this practice of mirroring their assessments.

Table 1.8: Percentage Agreement with Statements based on Stake Level

NBETPP Survey Results[1]	High Stakes	Low Stakes
Impact on Classroom Instruction and Assessment		
Greatly increased time spent on instruction in tested areas	43	17
Greatly decreased time spent on instruction in nontested areas	25	9
Created classroom tests in the same format as the state-mandated test	51	29
Used multiple-choice classroom tests on a weekly basis	31	17
Reported the state testing programs has lead teachers to teach in ways that contradict notions of good educational practice	76	63
Pressure to Raise Scores and Prepare Students for the State Test		
Strongly agreed they felt pressure from their district superintendent to raise scores on the state test	57	41
Strongly agreed they felt pressure from their building principal to raise scores on the state test	41	17
Strongly agreed that there is so much pressure for high scores on the state-mandated test that they have little time to teach anything not on the test	41	18
Spent more than 30 hours per year preparing students specifically for the state test	44	10
Prepare students for the state-mandated test throughout the year	70	43
Used test preparation materials developed commercially or by the state	63	19
Used released items from the state test to prepare students	44	19
Taught test-taking skills to prepare students	85	67
Impact on Teacher and Student Motivation and Morale		
Reported teachers at their school want to transfer out of tested grades	38	18
Strongly believed students are extremely anxious about taking the state test	35	20
Perceived students are under intense pressure to perform well on the state test	80	49
State test has caused students in their district to drop out of high school	28	9
Views on Accountability		
Inappropriate to use test results to award school accreditation	66	77
Inappropriate to use test results to evaluate teachers/administrators	82	90
Inappropriate to use test results to award teachers/administrators financial bonuses	87	96
Appropriate to use test results to award high school diplomas	57	37
Inappropriate to use test results to promote or retain students in grade	59	76

Source: Pedulla et al. (2003)

1. Differences between high and low stakes percents for each item are statistically significant (alpha = .001).

From Pedulla, et al., 2003

Another interesting difference between high and low stakes states was their use of specifically designed test preparation materials. 63% of high-stakes states teachers use materials that have been designed either by the state or commercially that are intended to prepare students for their exams, in contrast to only 19% of teachers in low stakes states. However, these materials may be somewhat more available in high-stakes states, leading to a greater level of usage (Abrams, et al., 2003). The original report determined numerous different areas where high-stakes and low-stakes teachers differed significantly. It is clear that the testing environment has a major impact on the form of assessment used by teachers.

Ireland has a high-stakes testing environment, and recent studies have shown the impact of this on students' learning experiences (Smyth, et al., 2011). In sixth year, students complete their Leaving Certificate examinations which determines, based on a points system, whether they can be accepted to the college course of their choice. Sixth year students have been found to be impatient with teachers who did not concentrate on the curriculum and to be critical of teachers who did not focus on exam preparation. The study clearly highlights that under the current high-stakes environment, the range of student learning experiences is narrowed by the Leaving Certificate as it focusses both teachers and students on 'covering the course' (Smyth, et al., 2011).

(e) Obstacles relating to understanding of assessments

A study involving pre-service primary school teachers in Scotland examined participants' knowledge of assessment methods (Maclellan, 2004). This study involved analysing 30 essays of 3500-4000 words in length which were in response to the question "What do you know about educational assessment that will help you in your teaching?" The number of paragraphs dedicated to topics was considered the unit of analysis in this study, and the topic sentence of the paragraph was coded independently by two researchers. The researchers determined that the PST involved in this study showed very little clear knowledge of assessment methods (Maclellan, 2004). If PST have little knowledge of various types of assessment methods that they can carry out within their classrooms, then it is likely that they will not attempt new or alternative methods.

Summary

The literature discussed in this section provided an overview of formative and summative assessment in inquiry. There are indications that traditional assessment, such as paper-pencil tests, is still favoured by many teachers. Further research is required on teachers' current inquiry assessment practices.

Much like in the case of implementing inquiry, there are various barriers that impede or discourage teachers from broadening their assessment practices. Teachers' misunderstandings of assessments which are rooted in tradition, time to change and implement assessment, assessing group work, and high-stakes environments are all barriers to changing assessment practices which have been identified within the literature.

Some of these barriers are under the control of the individual teacher and therefore there is a clear need to increase teachers' knowledge about alternative assessment approaches. Also, by identifying the role of assessment the teacher can modify their practices as required. Summative assessments need not drive all assessment; there is a need for formative assessments, and not just as many smaller versions of the summative model for assessment. This needs to be discussed with PST, particularly if they have come through a high-stakes testing environment where their own learning and assessment experience may have been narrow.

The next section examines professional development, the characteristics of successful programmes, and how such programmes could be evaluated.

1.3 Effective Teacher Professional Development

This section deals with teacher professional development at a general level. There have been several characteristics of successful professional development programmes identified within the literature and these are discussed here. Additionally, reasons that professional development reform fails are highlighted. Importantly, how to evaluate these programmes is also discussed. IBSE specific programmes are not discussed within this section. They are discussed in Section 1.4.

1.3.1 What is Professional Development

People from a wide range of careers take part in professional development (PD) to gain and apply new knowledge or skills that help them to improve their job performance. Little (1987) provided the rather broad view of teacher PD as "*any activity that is intended partly or primarily to prepare paid staff members for improved performance in present or future roles in the school districts*" (Little, 1987).

An alternative view of teacher PD programmes was provided by Guskey (2002), who states that they are "*systematic efforts to bring about change in the classroom practice of teachers, in their attitudes and beliefs, and in the learning outcomes of students*" (2002). This understanding of PD highlights the benefit to the students of the teachers undertaking the PD. PD programmes are believed to be essential for the implementation of new teaching strategies, in particular those where changes need to occur in teacher's classroom practices (Garet, et al., 2001).

PD programmes for teachers are made up of four key elements. The PD programme itself, the teachers, the facilitator of the PD programme who guides the teachers, and the context in which the programme occurs all make up a PD system (Borko, 2004). This is summarised in Figure 1.4.

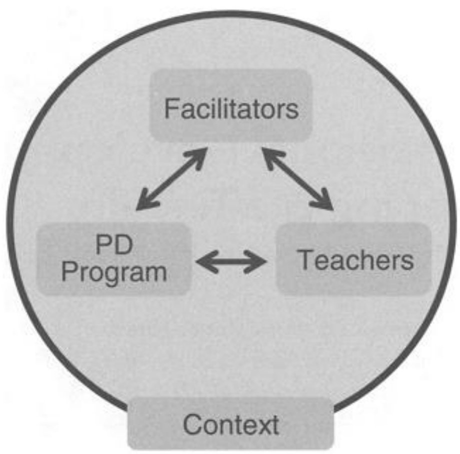


Figure 1.4: Elements of a Professional Development System
From Borko, 2004

There are two primary purposes of PD for improving teaching:

a) to fine tune a teacher's current skills, and
b) to master a completely new teaching strategy or set of skills.

This mastering of a new strategy is typically more difficult than fine tuning previously existing skills as the magnitude of change required is greater (Joyce & Showers, 1980). Fine tuning of skills needs to occur because PD is not a short-term process; rather, it is a long term process. PD begins when the teacher is completing their teacher education at university, and continues through to the workplace when they take part in in-service training (Putnam & Borko, 2000; Feiman-Nemser, 2001).

1.3.2 Characteristics of Successful PD Programmes

An early analysis of more than 200 studies by Joyce and Showers (1980) on PD programmes identified key features that contribute to the effectiveness of these programmes. The major success related components that were identified in the reviewed studies include:

1. *"Presentation of theory or description of skill or strategy;*
2. *Modelling or demonstration of skills or models of teaching;*
3. *Practice in simulated and classroom settings;*
4. *Structured and open-ended feedback (provision of information about performance);*
5. *Coaching for application (hands-on, in-classroom assistance with the transfer of skills and strategies to the classroom)"* (Joyce & Showers, 1980, p. 380)

It was noted that PD programmes can be most effective when several or all of the above components are included in the training. For programmes where teachers are fine-tuning pre-existing skills, modelling, and practice in simulated conditions and classrooms with feedback are suggested. Where a new skill or learning approach is to be mastered, presentations of theory behind the skill, and coaching with in-classroom assistance may be necessary in addition to the previously mentioned components (Joyce & Showers, 1980).

More recent research (Darling-Hammond & McLaughlin, 1995) on characteristics of effective PD programmes mirrors many of the identified components in Joyce and Showers work. Six characteristics were put forward which are based upon the premise that for effective PD, teachers must assume the role of both the learner and the teacher. The characteristics of effective professional development listed are:

1. *"It must engage teachers in concrete tasks of teaching, assessment, observation, and reflection that illuminate the processes of learning and development;*

2. *It must be grounded in inquiry, reflection, and experimentation that are participant-driven;*
3. *It must be collaborative, involving a sharing of knowledge among educators and a focus on teachers' communities of practice rather than on individual teachers;*
4. *It must be connected to and derived from teachers' work with their students;*
5. *It must be sustained, ongoing, intensive, and supported by modelling, coaching, and the collective solving of specific problems of practice;*
6. *It must be connected to other aspects of school change*". (Darling-Hammond & McLaughlin, 1995)

Guskey (2003) analysed lists of the characteristics of effective PD programmes. He looked at 13 lists published between 1995 and 2002 by researchers, agencies, teacher and education associations or organisations, and the U.S. Department of Education, to determine any commonalities. It was found that, of the 21 characteristics of effective professional development found, some appear on most lists, but none are included in all.

- The most frequently mentioned characteristic or principle, included in 11 of the 13 lists, was **enhancement of teachers' content and pedagogic knowledge.**
- Ten of the lists included the need for **sufficient time and other resources** as being integral to PD.
- The promotion of **collegiality and collaborative exchange** among teachers was highlighted in many of the lists.
- Several lists suggest that PD programmes or activities should be linked to **needs identified by the teachers** (Guskey, 2003).

Each of these points is now considered individually, under the headings (a) to (d) below; also discussed under (e) is the form of the activity.

(a) Enhancement of Content knowledge

In a 2001 study (Garet, et al., 2001), the effects of PD programmes, with various characteristics, on 1,027 mathematics and science teachers were determined. These teachers took part in the Eisenhower Professional Development Programme which was a federal programme supporting the professional development of teachers, primarily in the area of science and mathematics. It was found that content focus had a substantial positive effect on enhanced knowledge and skills amongst the teachers. This implies that greater emphasis on content is more likely to produce enhanced knowledge and skills (Garet, et al., 2001).

The GLOBE programme has been conducted with 24,000 teachers in the area of earth-science helped teachers to implement student-lead inquiry based instruction and protocols helping students take part in data collection. 454 teachers with diverse ranges of experience and backgrounds that took part in the professional development programme were surveyed following their training. They found that when the GLOBE content was emphasised during the training there was a positive relationship to how prepared the teachers were for inquiry-oriented instruction in the classroom (Penuel, et al., 2007).

Therefore, teachers need to act as learners in extending their own content knowledge.

(b) Provision of Time and Resources

Ample time is required for teachers to deepen their understanding, and develop new methods for instruction. The duration of PD can refer to the number of contact hours that the teachers have spent in the PD programme, and also to the span of time that the teachers are involved in the programme, be it days, weeks, or months. It has been found that time span and contact hours have a substantial positive influence on coherence. Coherence of a PD programme relates to whether it builds on what the participants have previously learned, if it emphasises content and pedagogy that is in line with national standards and frameworks, and if it supports teachers in developing professional communication with other teachers. Time span and contact hours also have a substantial positive influence on opportunities for active learning. Active learning might include the opportunity to observe, or be observed when teaching, or to plan a classroom implementation related to the material covered in the PD programme. Time span and contact hours also have a moderate positive influence on how much content knowledge is emphasised. This means, the greater the contact hours and time span, the more emphasis that is placed on content knowledge (Garet, et al., 2001). Content focus is one of the key factors in successful PD programmes.

Joyce & Weil (1986) have claimed that it takes at least 30 hours of training to perfect a new teaching method and make a substantial permanent change in practice (Joyce & Weil, 1986). From over 1,300 potentially useful studies, "What Works Clearinghouse Evidence Standards" (WWC) selected 9 studies of PD that met with their standards. Of these 9 studies, the PD programmes had durations of between 5 and 100 hours. The three studies which had the least amount of hours, consisting of 5-14 hours contact time, showed no statistically significant effects on the achievement of students. Studies with greater than 14 hours involved in the analysis showed positive significant effects on student achievement (Yoon, et al., 2007).

However, contrary evidence to this exists. Analysis of 12 PD studies by Kennedy (1998) demonstrated that differences in the duration of the PD were not related to improvements in student outcomes. The studies reviewed had contact hours that ranged from 2.5 hours to 150 hours. Some brief mathematics in-service programmes that were analysed demonstrated greater effects on student learning than other PD programmes that were much more time-intensive (Kennedy, 1998). This would be the case if a programme used a lot of time, but did not use it wisely.

Running a programme that is ineffective for a longer period of time does not necessarily make it any more effective. The discrepancies in Kennedy (1998) and Yoon et al.'s (2007) studies could be attributed to the WWC standards being overly rigorous, and perhaps their restrictive criteria may have eliminated good studies that may have altered the overall results.

(c) Promotion of Collegiality and Collaboration

Discussing teachers' situative learning, Borko (2004) highlighted the myriad of contexts in which teachers can learn:

"*For teachers, learning occurs in many different aspects of practice, including their classrooms, their school communities, and professional development courses or workshops. It can occur in a brief hallway conversation with a colleague, or after school* *when counselling a troubled child. To understand teacher learning, we must study it within these multiple contexts, taking into account both the individual teacher-learners and the social systems in which they are participants*" (Borko, 2004).

Collective participation and collaboration with other teachers allows the teachers the opportunity to discuss concepts, skills, and issues that may arise during and after the PD programme. This is particularly true of teachers who either work in the same school, department, or student class level. PD that focusses on teachers from the same school may help to maintain the changes and improvements in practices over time. Grouped PD can provide teachers with a common understanding of instructional practices, and solutions to problems, which will be sustained within the school if staff members leave, and new teachers join (Garet, et al., 2001). Activities which encourage teachers to partake in professional communication appear to support change in teaching practice (Garet, et al., 2001).

In a study involving Estonian teachers of chemistry, change in the teachers following an in-service course was determined. While all of the teachers involved in this study demonstrated some level of change following the intervention, the magnitude of change was greater in the instances where the participants worked as part of a team (Laius, et al., 2009).

Research from Little (1993) suggests that teachers should be able to discuss new practices with each other as the change is occurring. Teachers often state that working as part of a group over the course of a PD programme helps to motivate them to work through whatever problems they might come upon. This collective participation can help build a sense of community within the school that the teachers work in (Little, 1993). However, for collaboration to be of benefit to teachers, it should be structured with clear goals, as individuals can easily hinder progress just as easily as they can improve it.

(d) Learner Identified Needs

Many PD programmes suggest that to be successful, the organiser must first obtain a set of learner identified needs or goals that the participant hopes to have achieved following the programme. In a PD programme for pharmacists, they concluded that when developing a programme, identifying the needs of the learners is necessary. They state that the focus of most PD programmes is on new, and cutting edge developments, but they believe that there is also a need for more basic or corrective teachings to fill some skill gaps (Zubin, et al., 2006). The same could be said of the teaching profession. Although many educators may want to take part in PD focussed towards the latest technological advancements, or instructional methods, some teachers may feel that they have fallen behind their peers in other areas. The aim of this type of PD would not be to introduce teachers to new materials or practices, but to allow the participants an opportunity to catch up to their peers.

(e) Form of Activity

Although not on Guskey's list, the form of the programme has been highlighted as an important factor in developing a successful PD programme. The workshop is the most common form of PD programme. All of the PD programmes in Yoon et al.'s work that demonstrated an increase in students' learning were in the form of workshops or summer institutes (Yoon, et al., 2007). The primary focus of these workshops was on research-based instructional practices. The teachers were also afforded the opportunity to alter the practices to suit their own classroom environment (Guskey & Yoon, 2009). Further to this, the participants were involved in active learning experiences which are considered by many to be a characteristic of successful PD (Desimone, et al., 2002).

"*Workshops are not the poster child of ineffective practice that they are made out to be.*" (Guskey & Yoon, 2009, p. 496). The evidence in the literature seems to suggest that it is not the form of the programme that decides the success of the training, but the actual content and organisation of the programme itself.

1.3.3 Why some Professional Development Reform Fails

The purpose of PD, as discussed earlier, has been said to be related to attempting to change the attitudes and beliefs of teachers, their classroom practices and/or the learning outcomes of their students. Changing these factors is all part of educational reform, and as such, PD is an integral part of the reform process. Educational reform is not always successful however. Although the blame for reform failure cannot always be placed on PD, it certainly can play its part.

In an article by Fullan and Miles (1992), they presented seven basic reasons for why typical approaches to teacher reform fail. The first reason that they provide for reform failing is "*faulty maps of change*". Everyone involved in school reform – teachers, parents, stakeholders, etc. – has their own conceptions of how change happens. These pre-conceived ideas can hinder change in teachers and schools. For example, some parties may think that "*you just have to live reform one day at a time*", whereas others might believe that reform requires a mission, objectives, and a well laid out series of tasks or goals. One of these concepts promotes improvisation within teacher change, while the other extols the merits of structured and organised planning. If teachers are part of a well-structured PD programme and their "*map of change*" aligns with improvisation then this could jeopardise the reform.

A particular version of a faulty map, "*misuse of knowledge about the change process*", is a problem that can also cause reform to fail. Pre-conceived notions or half-truths about how change may occur can affect the reform process and lead to its failure.

The next reason provided that reform might fail is "*complex problems*". Solutions to a problem might not be easy or known, so PD may not be enough if this is not considered. "*Education is a complex system, and its reform is even more complex. Even if one considers only seemingly simple, first-order changes, the number of components and their interrelationships are staggering: curriculum and instruction, school organisation, student services, community involvement, teacher in-service training, assessment, reporting, and evaluation. Deeper, second-order changes in school cultures, teacher/ student relationships, and values and expectations of the system are all the more daunting*" (Fullan & Miles, 1992)

With problems this complex, "*impatient and superficial solutions*" could make matters worse. This is another reason put forward by Fullan & Miles (1992) which could be involved in reform failing.

Reform may also fail based on prioritising "*symbols over substance*". If reform is only being promoted and professional development is only being conducted so that it appears like efforts are being made to solve a problem, then change is unlikely to occur. This is because education reform can be a political process which may further the careers of some innovators if they appear to be helping to promote change.

"*Misunderstanding resistance*" was suggested as another potential for reform failing. If insufficient resources have been supplied or perhaps the PD is not appropriate, and this is mistaken for resistance from the involved parties, this diverts attention away from the real problems. If real issues with PD are not identified and addressed, then the desired change may not occur.

As a result of reform, there will be success stories. However, it is not enough for reform to achieve isolated pockets of success. For a reform programme to be successful it would generally require a lot of effort on the part of one, or all of the parties involved. However, this effort may not be sustainable over time. "*Attrition of pockets of success*" can be a reason for the failure of some reform programmes (Fullan & Miles, 1992).

1.3.4 Evaluating Professional Development

Guskey (2002) has said that there are three major ways in which professional development programmes are typically evaluated. Namely planning evaluation takes place before a programme begins, formative evaluation takes place during the programme, and summative evaluation is completed following the programme. The purpose of planning evaluation is to give those involved in the development an appreciation of what is to be achieved as part of the programme, and how it is to be evaluated. The purpose of formative evaluation is to give the programme organisers or the developer ongoing information as to whether progress is being made and outcomes are being achieved. Summative evaluation is used to ascertain what has been accomplished, the overall results of the programme, and in some instances, do the benefits outweigh the cost of the programme (Guskey, 2000).

In a paper not specific to teacher professional development, five levels of evaluation were suggested by Grace (2001) to ensure that a PD programme has achieved its requirements. The author discusses the need to ensure that the maximum benefit is achieved from PD otherwise it is simply wasteful. To do this, they say that the PD needs to meet certain requirements. The first such requirement is satisfying the identified needs, or learner specific goals, of the people involved. Next, the paper says that the PD should help the organisation to meet its objectives, make sure that it is evaluated to ensure that learning was achieved, and something must change as a result of the training that will preferably generate benefits to both the learner and the organisation.

The first level of evaluation suggested here is "*Reaction to the Event*" (Grace, 2001). Following training, evaluation forms are the typical method of determine the participant's reaction to the training. The author suggests that the forms should probe why the course was good or bad, not just *if* it was good or bad. The second level of evaluation is "*Were the objectives achieved?*" For this level of evaluation to be meaningful, the participants should have identified their objectives or learner specific goals prior to the training. To do this, there would have to be contact before the PD programme. Two or three days after the training is suggested as an appropriate time to ask if the participants' needs have been met and how they plan to put their learning into effect. The third level of evaluation is "*What has changed as a result of the training?*" This is the most important aspect of evaluation, as too often nothing changes. Change can also not be determined one or two days after the training. A few weeks after the PD event, participants should be evaluated to see if they have changed, as this time lag allows them to try out what they have learned. "*How has the training benefitted the team?*" and "*How has the training benefitted the organisation*" can be evaluated in the context of teaching by evaluating whether the change in a teacher's practice as a result of a PD programme has benefited student learning. This effect cannot be determined a day or two subsequent to the event. Therefore, an appropriate amount of time must be left before evaluating the final levels (Grace, 2001).

Guskey also suggests that there are five levels that are important to the evaluation process. Unlike Grace's five levels, Guskey's are aimed specifically towards educators. The five levels are participants' reactions, participants' learning, organisation support

& change, participants' use of new knowledge and skills, and student learning outcomes. Each level has different questions that need to be addressed. Information about these questions can be gathered in specific ways and this information helps to measure or assess different aspects of the professional development. The information obtained is used to inform or improve aspects of the training. Further information about these levels is contained in Table 1.9 (Guskey, 2000).

A model for evaluating teacher PD programmes has been suggested by Desimone (2009) which consists of the following four steps (see Figure 1.5):

1. *"Teachers experience effective professional development;*
2. *The professional development increases teachers' knowledge and skills and/or changes their attitudes and beliefs;*
3. *Teachers use their new knowledge and skills, attitudes, and beliefs to improve the content of their instruction or their approach to pedagogy, or both;*
4. *The instructional changes foster increased student learning"* (Desimone, 2009, p. 184).

With this model, the change in teachers' knowledge, attitudes, or practice, can be evaluated, as well as how these changes influence student learning or achievement. The author suggests that a common model for evaluating teacher PD should benefit the overall understanding and best practice for teacher learning programmes, as well as studies conducted on teacher PD (Desimone, 2009).

Table 1.9: Five Levels of Professional Development Evaluation

Evaluation Level	What Questions Are Addressed?	How Will Information Be Gathered?	What is Measured or Assessed?	How Will Information Be Used?
1. Participants' Reactions	• Did they like it? • Was their time well spent? • Did the material make sense? • Will it be useful? • Was the leader knowledgeable and helpful? • Were the refreshments fresh and tasty? • Was the room the right temperature? • Were the chairs comfortable?	• Questionnaires administered at the end of the session.	• Initial satisfaction with the experience	• To improve program design and delivery
2. Participants' Learning	• Did participants acquire the intended knowledge and skills?	• Paper-and-pencil instruments • Simulations • Demonstrations • Participant reflections (oral and/or written) • Participant portfolios	• New knowledge and skills of participants	• To improve program content, format, and organization
3. Organization Support & Change	• What was the impact on the organization? • Did it affect organizational climate and procedures? • Was implementation advocated, facilitated, and supported? • Was the support public and overt? • Were problems addressed quickly and efficiently? • Were sufficient resources made available? • Were successes recognized and shared?	• District and school records • Minutes from follow-up meetings. • Questionnaires • Structured interviews with participants and district or school administrators • Participant portfolios	• The organization's advocacy, support, accommodation, facilitation, and recognition.	• To document and improve organizational support • To inform future change efforts
4. Participants' Use of New Knowledge and Skills	• Did participants effectively apply the new knowledge and skills? • (How are participants using what they learned?) • (What challenge are participants encountering?)	• Questionnaires • Structures interviews with participants and their supervisors • Participant reflections (oral and/or written) • Participant portfolios • Direct observations • Video or audio tapes	• Degree and quality of implementation	• To document and improve the implementation of program content
5. Student Learning Outcomes	• What was the impact on students? • Did it affect student performance or achievement? • Did it influence students' physical or emotional well-being? • Are students more confident as learners? • Is student attendance improving? • Are dropouts decreasing? • (How does the new learning affect other aspects of the organization?)	• Student records • School records • Questionnaires • Structured interviews with students, parents, teachers, and/or administrators • Participant portfolios	• Student learning outcomes: • Cognitive (Performance & Achievement) • Affective (Attitudes & Dispositions) • Psychomotor (Skills & Behaviors) • (Student Work Samples) • State/Local Assessments) • (Performance Assessments)	• To focus and improve all aspects of program design, implementation, and follow-up • To demonstrate the overall impact of professional development

*

From Guskey, 2000

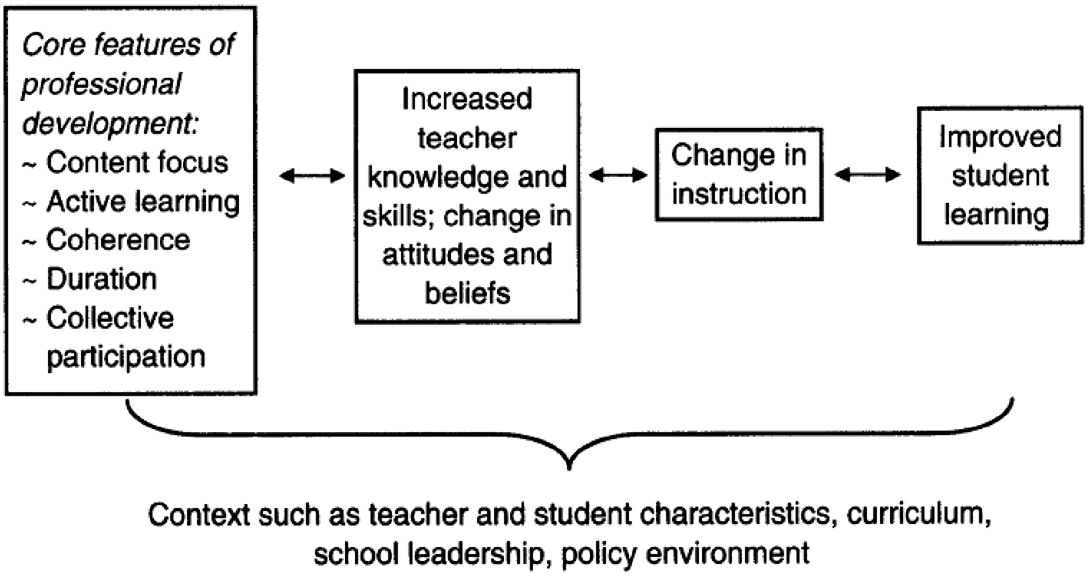


Figure 1.5: Conceptual Framework for Studying the Effects of Professional Development on Teachers and Students
From Desimone, 2009

Summary

Numerous different aspects of effective PD have been identified such as:

- An appropriate length of time for the programme;
- Collegiality during and after the programme;
- A focus on content knowledge and pedagogical content knowledge;
- It should be sustained over time.

Importantly, teachers' attitudes and beliefs about a particular reform are more likely to change once they have witnessed the benefits of the method for themselves. As such it is important that teachers try out what they have learned within the programme so that they can see an impact on their students' learning.

These findings have been used for the development and evaluation of teacher education programmes within the area of inquiry based science education.

1.4 Teacher Education Programmes in IBSE

Section 1.1 highlighted the benefits of the IBSE approach, but it also discussed the issues that prevent teachers from implementing inquiry in their classrooms. Changing teachers' assessment practices so that they are more appropriate for inquiry comes with its own challenges (Section 1.2). An important, yet often overlooked aspect of PST development is the observation that occurs throughout the entire childhood of the teacher-to-be. Whatever experiences that the PST has had throughout their own primary and secondary education, sets the bar for what they expect both student and teacher behaviour to be like, as well as the level of subject matter that must be tackled in school. As a result, they often adopt the practices of their former teachers (Kennedy, 1999).

The perceptions of PSTs play a part in how they gain knowledge during their teaching preparation. These perceptions can affect the pre-service teachers' classroom practice (Pajares, 1992). As was previously noted by Feiman-Nemser & Buchmann, *"future teachers cannot be expected to recognize that what they know about classroom life is only part of a universe of possibilities. They need help."* (Feiman-Nemser & Buchmann, 1983). Teachers need support if they are to change to inquiry based teaching. In light of this, this study aims to determine the impact of inquiry and inquiry assessment teacher education programmes on PSTs, so that the approach adopted within these programmes whereby the participants experience inquiry first hand can be mainstreamed into a module within initial teacher education.

Teacher PD has been proposed as a method for supporting teachers in implementing inquiry instruction in their science classrooms (Loucks-Horsley, et al., 1998). Over the years, various different training programmes have attempted to encourage teachers to use inquiry and to prepare and support them in their process of adopting inquiry in their classrooms. Much of the research in the area of inquiry teacher PD relates to in-service teachers as opposed to pre-service teachers, who are the target population of this study. Studies involving pre-service science teachers are discussed, but studies focussing on in-service teachers are also included so as to provide as much information in this area as possible. The limited number of studies involving PST in inquiry PD suggests the potential contribution to knowledge that this thesis can provide.

In a review of inquiry PD empirical research, the reported outcomes of 14 programmes were reviewed (Capps & Crawford, 2009). None of the programmes reviewed linked enhanced teacher knowledge with enhanced student knowledge, a change in teacher beliefs, and a change in their practice. However, the majority of these studies only focussed on one or two aspects. Programmes where teachers were immersed in authentic inquiry were more likely enhance teacher knowledge, prepare teachers to implement inquiry instruction, and lead to enhanced student understanding (Capps & Crawford, 2009).

When examining the research on inquiry PD at both in-service and pre-service level, it is clear that there are several approaches which have been tried with various degrees of success, for example experiencing inquiry first-hand and participants developing their own activities. These approaches to inquiry PD shall be discussed. Additionally, models for teacher change shall be discussed as it is useful to be aware of this when considering these programmes.

1.4.1 A Model for Change

Many professional development programmes are designed to change teachers' behaviours or student outcomes. The presumption is that once a teacher's attitudes and beliefs have been changed, specific alterations will occur in their classroom practices or behaviour, leading to improved student learning (Fullan, 1982; Guskey, 2002). Clarke and Hollingsworth (2002) have stated that this model of PD, which is based on a "*causal chain*", has teacher change as an implicit purpose. Teachers change their attitudes and beliefs, perhaps about a particular teaching methodology, which then leads to a change in their classroom practices, and the result is a change in student learning outcomes. This process is illustrated in Figure 1.6 (Clarke & Hollingsworth, 2002).

It is important to be aware that, for the majority of teachers, improving as a teacher means the enhancement of their students' learning outcomes. An early study examining teachers' perceptions of success found that, "*regardless of teaching level, most teachers define their success in terms of their pupils' behaviours and activities,* *rather than in terms of themselves or other criteria"* (Harootunian & Yargar, 1980). Therefore, what encourages teachers to seek out or take part in PD is the understanding that it will increase their knowledge and skills, which in turn will be of benefit to their students.

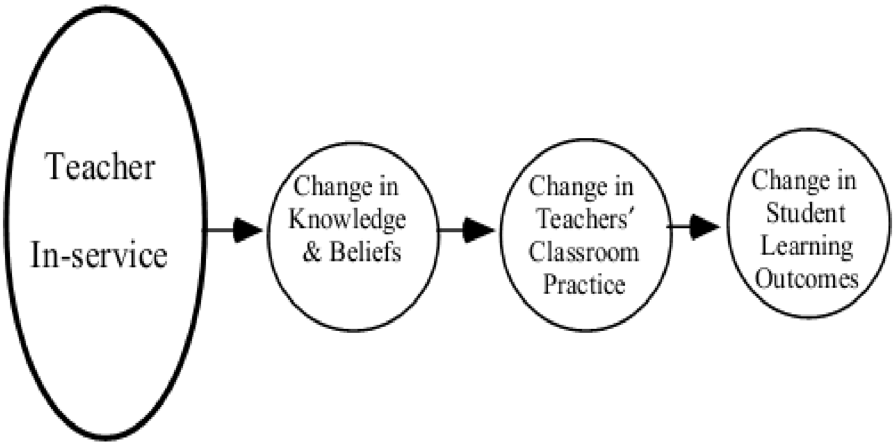


Figure 1.6: An Implicit Model of the Purpose of Teacher Professional Development
From Clarke & Hollingsworth, 2002

An alternative approach to teacher change from that shown in Figure 1.6 would involve the rearrangement of the processes involved in teacher change and focusing on changing teachers' classroom practices from the outset (Figure 1.7).

Guskey (2002) suggests that teachers' attitudes and beliefs will change when they have seen the benefits of a teaching approach; therefore teachers should be encouraged to address or try out their practices so they may see evidence of student learning which will ultimately change their attitudes and beliefs towards the pedagogy. According to Guskey (2002), "*the crucial point is that it is not the professional development per se, but the experience of successful implementation that changes teachers' attitudes and beliefs. They believe it works because they have seen it work, and that experience shapes their attitudes and beliefs"* (Guskey, 2002, p. 383).

It is the opinion of the researcher that Guskey's model for change is particularly important for PST who may not have an opportunity to trial practices within their own classroom. If PST can be taught through a particular method and they see it work for themselves, then that may help shape their attitudes and beliefs towards that method.

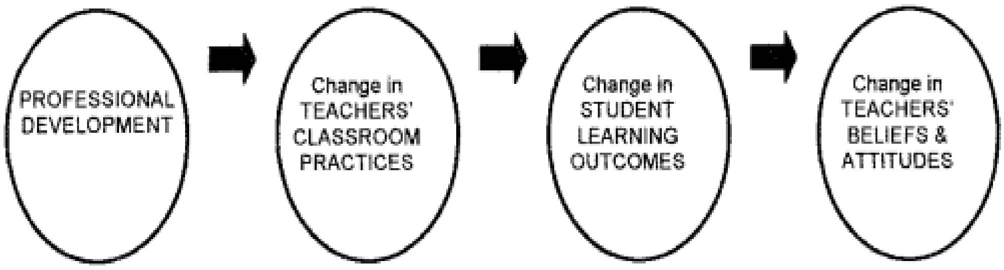


Figure 1.7: A Model of Teacher Change through Professional Development
From Guskey, 2002

1.4.2 Experiencing Inquiry First-hand

Inquiry PD programmes often do not observably help teachers to learn new inquiry abilities. In the NSES's inquiry guidelines, they propose that PD programmes aimed at inquiry should "*explicitly attend to inquiry – both as a learning outcome for teachers and as a way for teachers to learn science subject matter*" (NRC, 2000). Studies suggest that the majority of teachers have very little experience with actual scientific inquiry, and they therefore possess very inexperienced and informal notions about actual inquiry and inquiry in the classroom (Anderson, 2007; Windschitl, 2004).

The practice of immersing the participants in inquiry in the role of the students is a popular method of preparing in-service and pre-service teachers. Introductory workshops were organised which aimed to develop teachers' scientific and pedagogical content knowledge (Zion, et al., 2007). Instead of completing laboratory sessions and an ecology field project as was the norm, participants practiced authentic and open inquiry projects. They initiated and studied three inquiry questions that were related to each other. Participants of the programme could attend several follow up meetings per year. Here, the teachers discussed their implementation of inquiry in their classrooms, the obstacles they faced when implementing inquiry, and importantly, how they overcame these identified obstacles (Zion, et al., 2007).

The Verification of Inquiry and STEM Education Skills programme (Michalow, 2015) was a three semester programme based on the National Science Education Standards

(NSES). The participants were both pre-service elementary and secondary teachers taking part in a science methods course where they are given the foundations of STEM and inquiry-based education through classroom instruction. They took part in at least seven classroom inquiry and STEM activities throughout the semester (Michalow, 2015).

The ENVISION programme (Wee, et al., 2007) for training in-service teachers involved participants completing a month long summer institute in inquiry. Participants conducted field studies and collected data to research under specific environmental protocols. As part of the programme, teachers discussed the NRC inquiry standards, evaluated resources for teaching and assessing environmental science, and watched videos of other teachers in the classroom. They developed a plan with detailed descriptions of how they intended to integrate inquiry teaching into their instruction throughout the coming year. The researchers found that following the programme the teachers' ability to design lessons that reflected the National Science Education Standards increased, but not necessarily their ability to implement these lessons (Wee, et al., 2007).

The IBDC demonstration programme (Luft, 2001) was an 18 month PD programme aiming to change the beliefs and practices of induction and experienced teachers. Induction teachers are those that are pre-service, 1st year and 2nd year teachers. The programme addressed the specific needs of the learners, there were plenty of follow up opportunities provided to examine their learning of this new practice, and it fostered an environment where the teachers could connect this new information to other training programmes. The training began with a six day pre-programme, followed by a one day workshop which guided the participants into the idea of inquiry based teaching. This was later followed by a five day workshop where the participants took part in an extended inquiry cycle in the role of the students, whilst also developing their own inquiry cycle for use in their classrooms. There were four types of follow-up opportunities for the participants to further aid in the development of their inquiry teaching skills. First, teachers could observe other participants' implementation of an inquiry cycle, or the implementation of a demonstrator. Secondly, following observation by a programme coordinator or director, the teachers received feedback on their extended inquiry cycle observation. Third, teachers could attend five one-day meetings provided specifically to address the concerns of the participants. Finally, participants communicated with each other and programme staff electronically. This allowed for the sharing of ideas and reflection on aspects of their classes that they had implemented. Classroom observations showed positive change in the participants towards inquiry instruction; however the teachers' interviews showed that the teachers had traditional views. The induction teachers were slightly less likely to implement inquiry in their classrooms than the experienced teachers. The teachers' understanding and explanation of inquiry increased as a result of the programme. Teachers valued the extended inquiry cycles that they developed and implemented. When asked about their best teaching experiences from the year, teachers discussed the extended inquiry cycle that they implemented (Luft, 2001).

A small scale study (Lotter, et al., 2007). investigated 3 biology teachers that took part in a 2 week summer institute and 3 academic year workshops. The teachers took part in inquiry research activities in the role of students as part of the intervention. They also developed inquiry activities in topics that were considered hard to teach. During the second week of the summer institute the teachers taught the activities that they developed to their peers and the facilitators of the programme. They also took part in research that was ongoing within the university at the time. The change in teachers' practice and attitudes was evaluated using classroom observations and semi-structured interviews before and after the intervention. The interviews focussed on understanding the choices that teachers made whilst teaching their individual inquiry lessons. As a result of the programme, teachers better understood inquiry as a thinking process. Teachers discovered that inquiry didn't need to be a lengthy process in the classroom. However, teachers' prior core conceptions affected their implementation of inquiry in the classroom (Lotter, et al., 2007).

INSITE was a four year professional development project (Lehman, et al., 2006) which was aimed at helping teachers to employ project based, problem centred approaches in the science classroom. Each year of the project consisted of three distinct phases of training; these were a summer institute, implementation of project based units throughout the academic year, and a follow up for teachers during the next summer.

In-service and pre-service teachers completed a three week summer institute where they took part in a project-based activity where they modelled the experiences of the student within the inquiry classroom. Mini-workshops were presented to help teachers to develop pedagogical knowledge and skills. They participated in field trips to businesses and other sites where they could witness science in action and communicate with the scientists who worked there. The last aspect of the summer institute was working collaboratively with other teachers to develop project based units that could be integrated into their classrooms throughout the year. These projects would revolve around a particular theme from the Benchmarks for Science Literacy (American Association for the Advancement of Science, 1993). The teachers implemented these developed units during the academic year. Support was provided by an experienced practicing teacher who could provide guidance in the area of inquiry based science teaching by visiting classrooms, helping with lesson planning, etc. At the follow-up meeting, teachers discussed their implementation and revised their developed units for internet publication. The PD programme was evaluated using pre- and post- questionnaires, observations of classrooms, informal interviews with participants and staff, and surveys of students' attitudes towards the trialled project activities. The project was mostly successful at preparing teachers to implement inquiry in their classrooms. It was found that the summer institute was successful in promoting learner-centred attitudes towards teaching in the participants (Lehman, et al., 2006).

Teachers' lack of real life inquiry experience has encouraged several different PD courses, both in-service and pre-service, to include genuine inquiry experiences as part of their programmes in the form of longer research projects.

The IOWA Chautauqua program (Blunck & Yager, 1996) was a 3 week summer workshop aimed at moving in-service teachers away from a didactic teaching approach to a more constructivist approach by placing a focus on STS (Science, Technology and Society). As part of the programme, teachers conducted field experiences within the disciplines of biology, chemistry, earth science, and physics. Connections are made between science and the context of real world issues. Within the academic year, the teachers from the summer programme and a new batch of teachers could take part in two further 20 hour short courses and an interim project lasting between three to six months. The short courses covered many aspects of planning and teaching through STS, while the interim project involved planning an STS module including a variety of assessment strategies that would take at least 20 days to teach. As a result of the programme teachers became more confident teaching science, in aspects such as planning of science lessons, involving students more actively in their learning, and matching goals with curriculum and instruction. Additionally, teachers' understanding and use of the basic features of science improved, including focusing on questions, generating explanations from students and teachers, and student and teacher devised tests for determining the validity of explanations (Blunck & Yager, 1996).

The Teaching Science: Just Do It! (Melear, et al., 2000) pre-service programme was developed to educate PST of science in how to actually do science by having them conduct long term research projects. In this way they were immersed in an intensive inquiry experience which simulated what actually happens in a research laboratory. The seven pre-service teachers met formally for six hours a week and had open access to a laboratory and classroom. They attended weekly meetings and took part in a journal club where they would present a research article. Initially the participants were irritated and disillusioned due to the lack of guidance. As one participant pointed out they "*have been conditioned to follow the lead of the teacher*". However, they did come to realise the importance and relevance of what they were doing. One student admitted to being angry as a result of the class because they were "*a biology major who had never done any science. I thought it was bad that I had been in college for four years with no experience in a lab setting*". These frustrations can be seen as obstacles to those first introduced to inquiry. One student said that "*the main problem is ignition for all of us*". The feelings of irritation passed and it was suggested that they wouldn't have learned as much without this feeling. It made them work to discover more. The instructors have stated that for future programmes they would inform students of the potential for these feelings of irritation. The participants identified the key differences between this module and other traditional classes. They highlighted points such as being allowed to do science, thinking and using logic, going in their own direction, and several other features indicating active and autonomous learning. They also recognised that their own motivation determined whether or not they would learn in the class (Melear, et al., 2000).

1.4.3 Developing Inquiry Modules or Activities

The work discussed previously by Lotter, et al. (2007), the INSITE programme (Lehman, et al., 2006) and the VOISES programme (Michalow, 2015) all include the participants developing their own inquiry activity or module to help them learn about inquiry. Another programme to include this aspect in their approach was discussed by Crawford (2007). Five pre-service teachers carrying out a one-year placement in a second level Science Professional Development School (SPDS) had their knowledge, beliefs and efforts of teaching science as inquiry evaluated. The PSTs involved in this study were interviewed by university instructors and potential mentor teachers who hand-picked the PST they would work with. Together, the mentor teacher and PST co-planned and co-taught their classes. This was a form of cognitive apprenticeship to help the PST get to grips with and become accustomed to the process of inquiry teaching. As part of the programme the PSTs attended weekly seminars where they could share their struggles and successes. Initially the PSTs were enthusiastic and were ready to design inquiry based lessons, but this faded somewhat over the year, and eventually disappeared in some cases. A heavy work load of other teaching tasks, resistance from students, and the mentor's willingness to instruct through inquiry dissuaded the participants from teaching science as inquiry in their classes. The PSTs displayed widely varying practice despite them all being immersed in a programme where they learned about and worked with inquiry, and had mentors that knew the goals of the programme. Several of the PSTs did not have a clear idea how to carry out inquiry in the classroom and if the mentor had a particularly structured or rigid style then it prevented their student from conducting inquiry. However, "*a prospective teacher's personal view of teaching science as inquiry, comprised of his or her knowledge of scientific inquiry and of inquiry-based pedagogy and his or her beliefs of teaching and learning, is a strong predictor of a prospective teacher's actual practice of teaching science*" (Crawford, 2007, p. 636).

In Laius et al.'s (2009) study, the in-service programme that the chemistry teachers attended was aimed at developing the participants' skills for promoting inquiry, or their students' reasoning or creative thinking skills. The teachers were separated into two distinct study groups. Study A involved eight chemistry teachers who completed a PD programme aimed at fostering students' inquiry skills. Study B comprised of twelve teachers (eight chemistry, four biology) who attended a training programme that was aimed at fostering students' reasoning skills and scientific creativity. All of the teachers were provided with teaching or instructional resources which differed from Study A to Study B. Later in the intervention, teachers had to design their own resources which would include worksheets, a teacher's guide, an assessment guide, and any additional notes for teachers which could support the interdisciplinary features which would appear within the developed module. Following the intervention, six out of the eight teachers involved in the case study moved from a lower to a higher level of inquiry. The greatest aspect of change experienced by the teachers was in the area of teacher created instructional materials. Following the training, the quality of the materials created by the teachers was of a higher standard with respect to the inquiry process. The authors also commented that the change from standard practical work to authentic inquiry involved the participating teachers overcoming several constraints or barriers. Only the teachers who chose to tackle and overcome these issues moved on and succeeded in teaching through authentic inquiry (Laius, et al., 2009).

1.4.4 Delivery Formats

The Try Science! Programme (Harlen & Doubler, 2004) was a 13 week on-line Masters programme for elementary and middle-school teachers in inquiry-based science. A course with the same objectives and content was also delivered through a face-to-face programme. The on-line course had two aims; it was supposed to develop the participants' understanding of science and their pedagogical skills in relation to teaching through inquiry. About half of the course was studying aspects of inquiry based teaching and the other half was learning science content through the process of inquiry. The participants responded to the postings of others within their group. The first six weeks of the course was focussed on learning science and to do this the participants conducted investigations at home. After this, they spent some time reflecting on their own learning, thinking about children's learning and what is necessary to involve students' in their own learning. Towards the end of the programme, the participants designed and taught a short piece of inquiry which they discussed and evaluated on-line.

The participants in both versions of the programme increased their understanding of science content with the on-line cohort faring significantly better than the face to face cohort. Both groups believed that their understanding of inquiry had increased following the programme. The lesson plans produced by the participants envisioned students taking part in hands on activities and making their own predictions, but they were lacking in students investigating their own questions and students applying concepts. The participants of the on-line course spent approximately 90 hours on the course, whereas the face to face spent about 66 hours, 36 of which were when the cohort was required to be in class. The online cohort spent more time reflecting on their learning and on the inquiry process than the face to face group did and their collaboration online allowed them to feel like they were not alone. The confidence of these teachers in their ability to teach through inquiry increased over the course of the programme, with the on-line course increasing significantly (Harlen & Doubler, 2004).

Summary of Findings

The key features of inquiry programmes for in-service and pre-service teachers that have been reported in the literature or projects include:

Experiencing inquiry first hand:	as part of the programme
	or in extended projects
Group collaboration and support:	collaboration with peers
	support from Mentors
	interaction with online support
	teaching peers

Developing their own inquiry activity/ module

See exemplar materials

Teacher education programmes in IBSE should consider including these aspects within their inquiry programmes if they are hoping to increase the inquiry knowledge and classroom practice of their participants. However, more research needs to be conducted into programmes where several of these features are included to determine which combinations are most effective. Importantly, an aspect that is not typically covered in these programmes is guidance on how to assess the outcomes of inquiry lessons.

1.5 Overall Conclusions

This chapter discussed literature within the areas of inquiry based education, assessment, professional development, and inquiry specific teacher education programmes. Each of these sections has provided important information for the development of the research study.

A review of the literature on inquiry clearly demonstrates how it is carried out within the classroom and the benefits for students who have been taught using this methodology. Assessment in inquiry is an area that is of great importance when preparing teachers to teach through inquiry, and this chapter has highlighted some of the methods of assessment appropriate, and some of the obstacles teachers face when attempting to change their assessment practices.

In a broader sense, this chapter provides several lessons for the development of future teacher education programmes including the model for change to consider, the characteristics of successful programmes, and a discussion on why some professional development reforms have been known to fail.

An important conclusion from this research is that Guskey's model of change as described in Section 1.4.1 can be adapted to PSTs. Changes as a result of classroom practices cannot be seen by PSTs, but they can see the changes in their own learning which could impact their own attitudes and views. This model applies to the PD programmes discussed in Chapters 3 and 4, and to the development of the module described in Chapter 5.

Importantly, the research on inquiry specific teacher education programmes demonstrated some of the successful approaches for preparing inquiry teachers which can be incorporated within future programmes. Equally important was the absence of studies relating to pre-service teacher education programmes in inquiry. This suggests that this is an area that requires further detailed study.

In light of these conclusions, the following research question has been developed:

What is the influence of focussed teacher education programmes (TEPs) on pre-service science teachers' (PST) inquiry and assessment approaches?

To answer the main research question, the study was divided into three phases, and each of these is dealt with sequentially.

1. Determination of PSTs' understanding and views of inquiry practices, and how these change following an inquiry teacher education programme.

2. Determination of PSTs' understanding and views of assessment in inquiry practices, and how these change following incorporation of assessment within an inquiry TEP.

Informed by the answers to phases 1 and 2 above,

3. How can PSTs be supported in the development of their knowledge and views of inquiry in an undergraduate chemistry laboratory module?

Chapter 2 presents the methodology used in developing answers to these questions.

Chapter 2 - Methodology

The overall purpose of this study is to examine the understanding of inquiry and assessment of inquiry learning by PSTs across Europe and to use this to support the development of PSTs' knowledge and attitudes towards inquiry as part of a chemistry module. Section 1.5 discussed the overall research question of this study and the distinct phases that the question has been divided into. This chapter describes the methods and procedures used to address the research question and the primary data collection methods and tools used in this study are discussed.

2.1 Background of chosen methodology

Due to the nature of the objectives within this study, it was deemed appropriate to use different methodologies to tackle the different areas. When looking at the research questions, information about inquiry and inquiry assessment practices was more suitably determined using a quantitative method, whereas a more in-depth study of an inquiry based approach to teaching, learning and assessment within a PSTs' educational programme is more appropriately approached using a case study. As stated in Section 1.5, the study was carried out in three phases, phases 1 and 2 informed by quantitative data and phase 3 by the case study.

A common research methodology used in education is the quantitative analysis of data. In education research, analysing this data could involve the classifying or measuring of behaviour. Phases 1 and 2 were conducted utilising a survey design method to obtain quantitative data. Quantitative questionnaires were chosen as the method for phases 1 and 2 for several reasons. In the literature, House (1994) specifies that the use of questionnaires can give more defined, clear, and predetermined identification and measurement of variables than other methods. Although complex to construct and based on the honesty of respondents, they can be quickly accomplished and generate reliable conclusions with reportable findings which include percentages of variable occurrences (Bouma, 2000; Berg, 1989). When using questionnaires, validity and reliability need to be considered.

Validity of a questionnaire is the degree to which it measures what it is intended to measure. Questionnaires should address all aspects of the areas being studied. Face validity and content validity are two important validity issues which need to be considered. Face validity checks that the questionnaire seems to measure what it is intended to measure (Drost, 2011). Content validity checks that there are enough relevant questions to cover all of the aspects which are being studied. Testing content validity is based on judgement as no other objective method exists (Bollen, 1989). The burden then falls on the researcher to select indicators that thoroughly cover the particular concept such that it will be accepted by his/ her peers. In addition to the researcher, one of the best methods of ensuring validity is using experts from the area to ensure that the items are appropriate (Drost, 2011).

Reliability of a questionnaire refers to its ability to obtain the same data if it is administered again under the same conditions. In other words, it is the extent to which the measurement is repeatable (Bollen, 1989). Determining the internal consistency is one of the typical methods to estimate reliability (Drost, 2011). Cronbach's Alpha is the most popular method of testing for internal consistency and it is useful for estimating reliability once a factor or construct has been determined (Cortina, 1993).

In addition to the reasons suggested in the literature, questionnaires were deemed appropriate due to the nature of the participants involved in this research. PSTs from across Europe make up the sample of this research in phases 1 and 2, and as such observations and personal interviews would not have been suitable. Interviews and open questions would have implications for reliability and validity as translation of responses could lead to misinterpretation. Questionnaires translated by science education experts who are fluent in English, with "tick-box" responses were much more appropriate to achieving these goals.

A key criticism of the quantitative approach is that the area of science education involves relationships between teachers, students, and various other parties that cannot always be readily explained or clarified in quantitative terms. Over the past thirty years or so, qualitative research has been promoted as a valuable method for examining these relationships (Doyle, et al., 2009).

The research method employed in the third phase was a case study. Miles & Huberman (1994) consider a case as "*a phenomena of some sort occurring in a banded context*" which essentially means that once a researcher can specify the phenomena of interest and describe its boundaries then it can be defined as a case. The case study approach aims to capture the complex nature of a particular case in a specific setting and aids in the in-depth understanding of the case (Stake, 1995).

A core aspect of the case study approach is that the researcher must gather data from multiple sources and combines the statistical trends from quantitative data with in-depth detail provided by qualitative data and the joint strength of these methods provides a greater understanding of the problem than either method could provide alone (Creswell, 2014). In education, qualitative methodologies aim to explore the various complex phenomena encountered by teachers, students, school management, and policy makers. The philosophy and basic principles of quantitative and qualitative methodologies differ widely, and this is evidenced by the fundamental differences in the type of study aims, questions, design, and the method of data collection. Attempting to gain an in-depth understanding of phenomena and participants' viewpoints, avoiding any disruption to participants in their natural settings, and describing the findings of the research in a literary style which is rich in comments and clarifications from those involved in the study are the main features of qualitative research methodologies (Streubert-Speziale, 2007).

The case study is primarily quantitative but uses qualitative methods to obtain much of the data. Recently the mixed methods approach has become favourable with researchers as they believe that this approach can overcome the disadvantages that a single method has on its own (Creswell, 2003; Tashakkori & Teddlie, 1998). However, the in-depth nature of the case-study approach leads to its primary limitations which is that findings from a single case study are not very generalizable and there is less experimental rigor (Yin, 2014).

The case study methodology fit the needs of this study, which was to describe the development, teaching and learning in a chemistry lab module aimed at PST of science. This constitutes a "banded context" which can be studied using a case study approach.

This single-case study design was chosen due to the unique nature of this laboratory module. The module studied was developed and analysed based on the results of phases 1 and 2, presented in Chapters 3 and 4 respectively, and will be discussed in further detail in Chapters 5 and 6.Ethical approval was obtained from each participant prior to completion of the questionnaires (as per SAILS and ESTABLISH projects).

2.2 Research Phases

The overall question for this study is “What is the influence of focussed teacher education programmes (TEP) on pre-service science teachers’ (PSTs’) inquiry and assessment practices?” This study consists of three phases (discussed in Section 1.5) and the data for each of these phases was obtained in three distinct ways. The focus, tools, and methods of each of these three phases are displayed in Figure 2.1.

The top left box in Figure 2.1 refers to the overall question of the thesis. Each box below that along the left side of the diagram refers to a distinct phase of the study. For each phase of the study, following the arrows, the box to the right refers to the tools used to collect data for that phase, such as pre and post questionnaires. Following the arrow to the right again, the boxes on the right of the diagram refer to the overall methodology used for that particular phase.

To answer these research questions, data was collected and analysed at different stages. For the first phase, data was collected from PSTs within the ESTABLISH project (ESTABLISH, 2014) and analysed to determine PSTs’ understanding of inquiry and the changes that can be achieved through IBSE PD programmes. Pre and post questionnaires were used here to determine information on PSTs’ understanding and views of inquiry practices prior to and following focussed inquiry TEPs.

The next phase related to PSTs’ understanding and views of assessment and inquiry practices. As no suitable tools were found to have been developed and trialled already, the second phase of this research involved the development of tools aimed at determining PSTs’ understanding of assessment in inquiry and the changes that can be achieved through inquiry and assessment in inquiry PD programmes. This was carried out within the context of the SAILS project (SAILS, 2016).

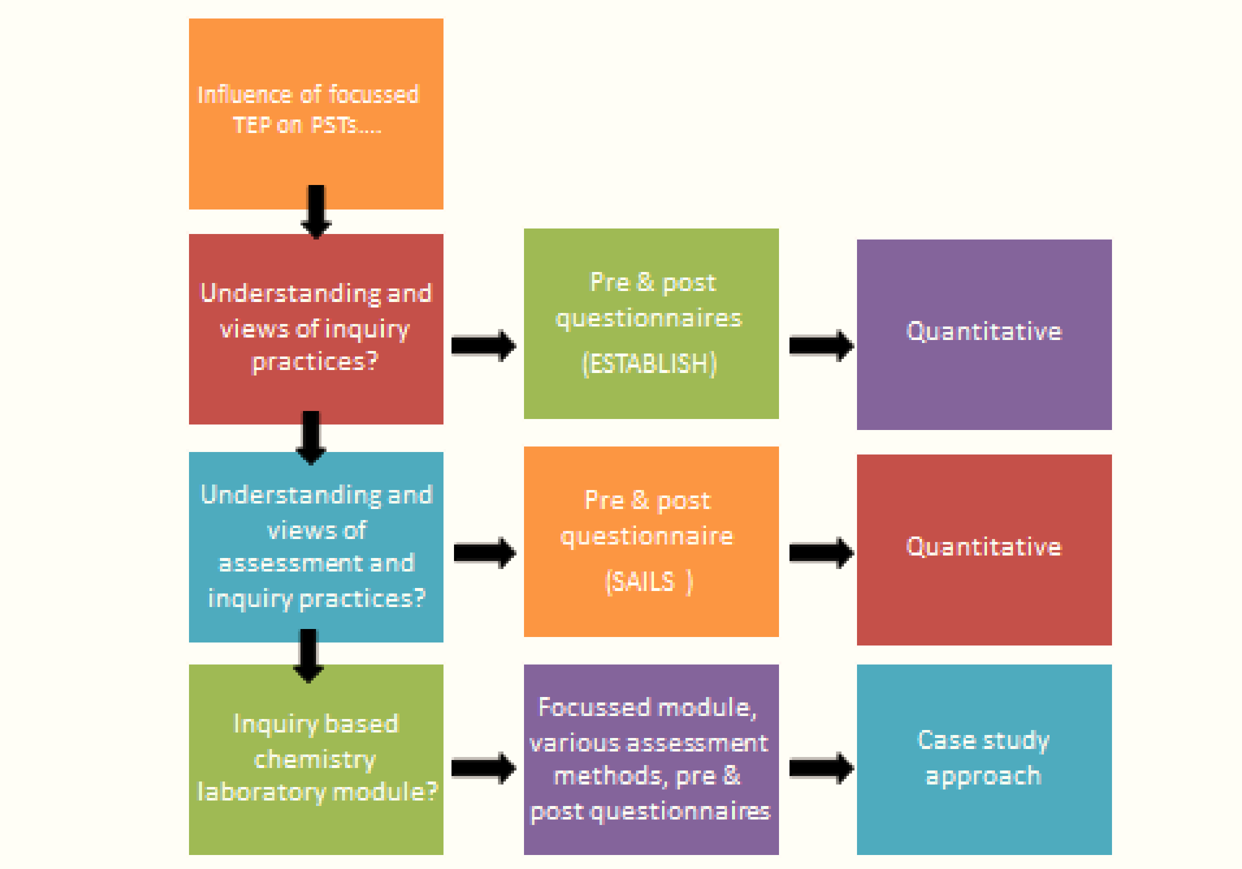


Figure 2.1: Research questions and approaches taken

The latter part of this phase of the research involved the collection of the data from the European partners who carried out SAILS TEP and the analysis of these results.

The final phase (phase 3) involved the development and implementation of a laboratory module based on the results from the first two phases which aimed to model and evaluate the impact of an inquiry approach to teaching, learning and assessment within a pre-service educational programme. The data collection for this phase occurred during the implementation stage. The methodology of the development and evaluation of the case study from the third phase of this study is discussed in detail within Chapters 5 and 6. The workflow for the different segments of the work is shown in Figure 2.2.

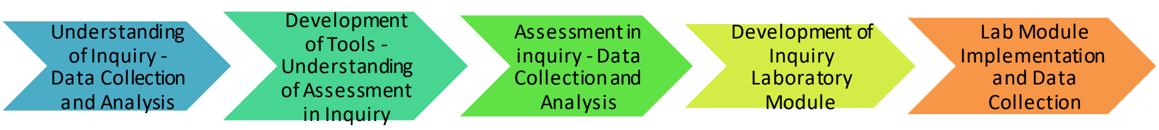


Figure 2.2: Workflow diagram showing Segments of Research

2.3 Context of the research and sample

Phase 1 of the study, which dealt with determination of PSTs' understanding and views of inquiry practices, and how this changes following an inquiry TEP, was carried out within the context of the ESTABLISH project. The ESTABLISH (European Science and Technology in Action: Building Links with Industry, Schools and Home) project, which was funded by the European Commission, was set up to support pre-service and in-service teachers across Europe in adopting inquiry based approaches in their classroom practice. The ESTABLISH consortium of over 60 partners from 11 European countries which was coordinated by DCU, worked together on this four year project (2010-2014) to encourage and promote the more widespread use of IBSE in second level schools. Members of the consortium ran inquiry PD programmes and worked with their local teachers to develop and implement IBSE units and evaluation tools. Data was obtained from 367 PST as part of this study. The 367 PST involved in this phase were those who had taken part in the ESTABLISH TEPs in Europe, and who had adequately completed the provided set of questionnaires. This sample was also chosen as data from this group would provide the required information on PSTs' understanding of inquiry and their views of inquiry before and after inquiry TEPs.

Phase 2 of this study, which dealt with determination of PSTs' understanding and views of assessment in inquiry practices, and how this changes following incorporation of assessment within an inquiry TEP was carried out within the context of the SAILS project. The SAILS project (Strategies for Assessment of Inquiry Learning in Science) was funded under the EU Framework Seventh Programme (2012-2015) and was coordinated through DCU. The SAILS consortium consisted of thirteen partner organisations, including universities, SMEs and a multi-national organisation, from across twelve European countries. SAILS objectives were to engage teachers in teaching and assessing through inquiry, allowing teachers to become more confident and competent to teach science through inquiry and assess skills developed though inquiry in their classrooms. To this end, a series of TEPs were developed and implemented within the SAILS project. Data was obtained from 269 PSTs as part of this study. The 269 PSTs involved in this phase were those who had taken part in the SAILS TEPs in Europe, and who had adequately completed the provided set of questionnaires. This sample was also chosen as data from this cohort would provide the required information on PSTs' understanding of, and practices within assessment of inquiry both before and after focussed TEPs.

The third phase of this research was carried out with a cohort of PST within the researcher's university. The module selected was a chemistry laboratory module of 33 hours (11weeks x 3hrs) given to 2nd year undergraduate PSTs who would ultimately be qualified to teach biology and physical education to leaving certificate level and science to lower second level. This module was chosen as it was a content based and laboratory module and the participants were chosen as they were novices within the subject of chemistry. This was desirable as the module was aimed at both content and laboratory aspects. Additionally, as the cohort was learning chemistry for the first time, they were quite similar to students at second level who would be encountering topics for the first time through inquiry. Another important aspect of the sample was that they had not been on teaching practice and as such they had not developed a preferred teaching strategy or any particular habits.

2.4 Description of Phase 1 Questionnaires

Questionnaires were developed by the ESTABLISH partners which were aimed at determining the following information about European PSTs:

1. Backgrounds of the participants in terms of age, teaching experience, etc.;
2. Understanding of inquiry;
3. Views of inquiry;
4. Self-efficacy in the inquiry classroom;
5. Views of teaching science;
6. Challenges in inquiry teaching.

The questions were developed with the aid of science education experts which ensured that the questions were valid and suitable for providing appropriate information. However, minimal trialling was carried out and no statistical testing was employed to determine if there were questions that did not "fit" with the primary constructs or if there were multiple questions which were asking essentially the same things.

Two versions of the questionnaires were produced, one given to participants for completion prior to the TEPs, and the second to be completed following their participation in the programme. The questionnaire given to the PST initially (pre-questionnaire) consisted of 48 questions. This questionnaire can be found in Appendix A.1 (Establish Initial Questionnaire). The questionnaire given to the PST finally (post-questionnaire) consisted of 29 questions, and is given in Appendix A.2 (Establish Final Questionnaire).

The majority of the questions included on the post questionnaire were included in the initial questionnaire, which allows for analysis of change in understanding and attitudes following participation in the TEPs. However, 18 items included in the initial questionnaire did not appear in the post questionnaire, so there were several areas where change could not be determined.

The ESTABLISH Pre questionnaire was subjected to a factor analysis but suitable factors were not determined. It is likely that this is due to the fact that not enough trialling was carried out initially. Therefore, the individual questions in the questionnaire were grouped into similarly themed questions and the data were analysed under these headings. These groupings were discussed with science education experts and deemed appropriate. These topic groups are:

- Understanding of inquiry
- Attitudes towards inquiry in the classroom
- Views of “good” teachers of science
    - Pedagogy
    - Development of content knowledge
- Self-efficacy in the inquiry classroom
- Attitudes to science outside of the classroom

2.5 Development of Phase 2 Questionnaires

Questionnaires were developed for in-service and pre-service teachers who took part in the SAILS programme. The in-service questionnaires were developed initially, and informed the development of the pre-service questionnaires. While the results of the in-service questionnaire analysis do not form part of this thesis, the development of the questionnaires used in the evaluation of in-service programmes informed the development of the questionnaire for the PST programme. Certain considerations need to be made for PST which are unnecessary for in-service teachers. These aspects were considered during the development of the pre-service questionnaires.

2.5.1 In-service SAILS questionnaire development

The questionnaires for the in-service teachers were developed by the researcher with the guidance of several science education experts. The TEPs were intended to prepare teachers to teach through IBSE and to be confident and competent with assessing their students' learning. The teachers should be familiar with different assessment strategies so that they could evaluate a number of key skills and competencies that are developed in the classroom. The following were the key points of information that were required from the participants through questionnaires:

- The teachers' understanding of inquiry assessment;
- The teachers' inquiry and inquiry assessment practices;
- The overall effect on the teachers as a result of the IBSEA (Inquiry based science education and assessment) TEP;
- The overall effect on the teachers' attitudes to assessment as a result of the IBSEA TEP;
- The main constraints experienced by the teachers in changing assessment practices.

Questionnaires were developed as no available instrument suited these purposes exactly. For the in-service teachers, four instruments were developed and trialled before the final version was produced. To ensure validity and reliability of the questionnaires as far as possible, the questionnaires were subjected to various trials with samples of teachers, interviews with these teachers following their completion of the questionnaires, and group discussions with science teacher educators. This process was repeated until issues were no longer arising and the instrument was found to be appropriate. Initially, a pilot questionnaire was developed, containing 5 sections, which was trialled with a group of teachers attending a Summer School in Ireland and Portugal. Some difficulties with items in the questionnaire were raised which suggested that the teachers did not have the same understanding of terms such as "scientific literacy" and "scientific reasoning" as was required for the questionnaire. Interviewing some of the participants revealed that several of the terms used for elements of inquiry were confusing and there was not a unified idea about what each term meant, even though a glossary of terms was provided as part of this instrument. Further to this, there was no way to distinguish from the questionnaire whether teachers were using some practices as teaching methods or just assessment methods.

To ensure that items could be understood by the participants, it was decided that the majority of inquiry statements be taken or adapted from an instrument which has already been successfully trialled and developed. As these questionnaires built on those already used in ESTABLISH, the aspects which were appropriate were maintained. The Principles of Scientific Inquiry – Teacher (PSI-T) was selected as appropriate to incorporate into the next iteration of the questionnaire (Campbell, et al., 2010). Additional items were developed which addressed the social and collaborative nature of inquiry in the classroom, and understanding of assessment in inquiry.

The final version of the pre- questionnaire was trialled on a very small scale (n = 3) in Ireland but it was clear that the instrument took too long to complete, certain statements were not clear to the participants, and the feedback sections appeared detached from the inquiry aspect which we were attempting to capture. Changes were made so that unclear statements were removed, feedback items were directed more towards inquiry, and sections that were time consuming but provided little information towards the primary goals of the questionnaires were removed.

The thoroughness with which this was carried out produced questionnaires that were deemed valid and thus suitable for use by a panel of science education experts. The edited versions were finalised and circulated to the members of the SAILS consortium. A copy of these questionnaires can be seen in Appendices A.3 (SAILS In-service Teacher Questionnaire – Initial questionnaire) and A.4 (SAILS In-service Teacher Questionnaire – Final questionnaire).

2.5.2 Pre-service SAILS questionnaire

A pilot questionnaire for PSTs was developed based on the final version of the in-service questionnaire. The following were the key points of information that was required from the PST:

- The PSTs' understanding of inquiry assessment;
- The PSTs' inquiry and inquiry assessment practices;
- The overall effect on the PSTs as a result of the IBSEA (Inquiry based science education and assessment) TEP;
- The overall effect on the PSTs' attitudes to assessment as a result of the IBSEA TEP;
- The main constraints to assessment identified by the PST;
- The PSTs' attitudes towards assessment feedback.

Although similar to the in-service questionnaire, the pre-service questionnaire was also trialled and reviewed several times before being approved by a panel of science education experts to ensure validity. Items relating to feedback which were included in the pre-service questionnaire but not on the in-service questionnaire were based on items from previously trialled and developed instrument (Brown, et al., 2012).

A draft questionnaire was developed and trialled with a small group of teachers (n=3). These teachers were interviewed to discuss their responses, and as a result of that there was a redraft to address any ambiguous questions. The primary issue with the pilot questionnaire was that the responses from teachers with classroom experience and responses from teachers without classroom experience would be different.

In the next version, students selected whether they had or had not teaching experience. This was included so as to distinguish between the two sets of participants to enable comparative analysis. The two groupings might produce distinctly different results, so a method of separation is necessary. It was also decided that all of the questions included in the pre questionnaire were required for the post questionnaire. There were also no additional questions that were needed for the post questionnaire. This was re-trialled which eventually produced the final draft. At each stage of the development the questionnaires were reviewed by science education experts. In this way it has gone through an iterative process and was deemed to be valid. As such, the questionnaire was deemed suitable for use as the final questionnaire. A copy of this questionnaire can be seen in Appendix A.5 (SAILS Pre-service Questionnaire – Initial & Final). Factor analysis was carried out on the questionnaire, and Cronbach's Alpha for each factor will be given in Chapter 4.

2.6 Description of Phase 3 Questionnaire

A questionnaire was developed for pre-service teachers who took part in a chemistry laboratory module. A questionnaire was required to determine the participants' views of inquiry, science teaching, and comfort in the inquiry classroom, and if these change following participation in the chemistry laboratory module.

A questionnaire was adapted for use within this phase which was primarily a combination of two previously developed and trialled questionnaires. These questionnaires were chosen as the items targeted information linked to the key objectives of this module. The majority of the items were informed by the "ISTEBI" questionnaire which is the Inquiry Science Teaching Efficacy and Beliefs Instrument initially produced by MaKinster (2000). This questionnaire was validated by Avery and Meyer by correlating with similar questions on a post survey and student interviews (Avery & Meyer, 2012). Four items were removed from the ISTEBI questionnaire before use. Three of these items were related to pre-service classes and elementary science, and one item was very similar to others previously asked and was eliminated.

The Relevance of Science Education (ROSE) questionnaire was designed to determine information about students' experiences and interests related to science inside and outside of school (Jenkins & Pell, 2006). Three items from this questionnaire were chosen to determine information about the pre-service teachers' beliefs about scientific theories and their attitudes towards school science.

The same questionnaire was used for both the pre and post questionnaire as it was important to determine any changes in all of these items (Appendix A.6 Case Study PST Questionnaire).

2.7 Quantitative Analysis

Data from the questionnaires was coded and input into specifically designed excel sheets given to all of the participating partners. This data was then gathered together by the researcher for analysis. The data from all the questionnaires were analysed statistically using IBM SPSS statistics 21.0. The primary statistical tests used and their purposes shall be discussed in this section. Statistical analysis was used to analyse the data from all three phases. The analysis was carried out primarily to determine changes in participants' responses over the course of TEPs and differences between different groups of participants such as those with different experience level or teaching experience.

The responses to the questionnaires were primarily based on 5-point Likert-type scales. Non-parametric tests are performed on data that are measured on nominal or ordinal scales. This is data that are typically classified into categories, for example high, medium and low IQ, or in this case Likert-type questions where responses are "strongly agree" to "strongly disagree", for example. Non-parametric or distribution free tests are named in this way due to the fact that the do not depend on assumptions about the specific nature of the distribution of the sampled populations (Bryman & Cramer, 2005; Gravetter & Wallnau, 2009). Therefore the three main statistical tests used are the Kruskal-Wallis test, Wilcoxon Signed-Rank test, and Spearman's Rho test which are non-parametric methods of analysis. These will be discussed in Sections 2.7.1, 2.7.2, and 2.7.3, respectively. Multi-dimensional scaling is also used within this thesis and will be discussed in Section 2.7.4.

2.7.1 Kruskal-Wallis Test

The Kruskal – Wallis test is the non-parametric alternative to the One-Way ANOVA test. It is used to evaluate differences between three or more conditions or populations using data from an independent-measures design. Where the One-Way ANOVA test requires the calculation of means and variances of data, this test simply requires that the individuals in the data can be rank ordered for the variable that is to be measured. The independent variable should comprise of two or more categorical and independent groups. Typically this test is used for three or more groups, but it can be used for just two (Lund Research Ltd., 2013). The test statistic for Kruskal-Wallis is given by:

$$K = (N-1)\frac{\sum_{i=1}^{g} n_i(\bar{r}_{i\cdot} - \bar{r})^2}{\sum_{i=1}^{g}\sum_{j=1}^{n_i}(r_{ij} - \bar{r})^2},$$

where n_i is the number of observations in group *I,* r_{ij} is the rank of observation *j* from group *I*, and N is the total number of observations across all groups.

Kruskal-Wallis testing involves the ranking of data to determine differences. The mean rank is obtained when the data is ranked in order, split back into two groups and then the mean of the groups is obtained. The Kruskal Wallis tests if there are significant differences between the mean ranks of the groupings. The $\chi^2(2)$ value generated and shown within tables throughout this thesis is the chi-squared value. The Kruskal-Wallis test statistic is approximately a chi-square distribution and if the calculated value of the Kruskal-Wallis test is greater than the critical chi-square value, then the null hypothesis can be rejected and it can be said that the sample comes from a different population. The critical chi-squared value is obtained from the degrees of freedom, which is one less than the number of groups ($k - 1$) and the p value. For $p = 0.05$ and 1 degree of freedom the critical chi-squared value is 3.84.

Therefore, within Chapters 3, 4 and 6, for each item with significant differences, values will be shown for p, $\chi^2(2)$ and mean rank. Significantly different items have a p value of less than 0.05 and a chi-squared value greater than 3.84. The mean rank for each group is shown which highlights the differences between the two groups.

2.7.2 Wilcoxon Signed-Ranks Test

The Wilcoxon Signed-Ranks test is the non-parametric alternative to the dependent t-test. The dependent t-test, otherwise known as the paired t-test, involves null hypothesis significance testing. The null hypothesis is that the mean difference between two paired samples is the same. If this is the case, then the two groups have to be equal. The paired t-test and Wilcoxon Signed-Ranks test are repeated measures tests. This means that there is one sample population involved in the study, but they are measured twice. The difference between the measurements for each individual is taken as the score for that participant. Much like the Kruskal–Wallis test, the Wilcoxon Signed-Ranks test requires the ranking of data. Each participants' individual score is rank-ordered from lowest to highest in terms of their absolute magnitude (Wright & London, 2009; Gravetter & Wallnau, 2009).

Wilcoxon Signed-Rank tests ranks the data and compares the responses of the participants to determine what the difference between the two data sets is. This test statistic is then converted into a z-score which is a value from a normal distribution. 95% of *z*-scores fall between –1.96 and 1.96 so for a significant difference to be determined at p = 0.05 for a two-tailed non-directional test, the z score must be greater than +1.96 or less than -1.96.

Therefore, within Chapters 3, 4 and 6, for each item with significant differences, values will be shown for p and z. Items where there are significant differences between the responses have a p value of less than 0.05 and a z-score greater than +1.96 or less than -1.96.

2.7.3 Spearman's Rho

The Spearman's rank-order or Spearman's Rho correlation is the nonparametric equivalent of the Pearson product-moment correlation. Spearman's correlation coefficient (r_s) is used to measure both the strength and direction of association between two ranked variables. The association is based on ranks of scores rather than on the raw scores themselves (Kornbrot, 2014).

This statistical test is a useful tool as it is appropriate when either or both of the variables are direct rankings or only ordinal. It is also appropriate when both variables are metric but not normally distributed, or when the relation between the variables is monotonic but nonlinear (Kornbrot, 2014).

The Spearman correlation coefficient, r_s, produced can give values from +1 to -1. If an r_s of +1 is obtained then this indicates a perfect association between the ranks. Conversely, an r_s of -1 indicates a perfect negative association between the ranks. Finally, an r_s of zero indicates that there is no association observable between the ranks and the closer r_s is to zero, the weaker the association between the ranks (Lund Research Ltd., 2013).

Therefore, within Chapters 3, 4 and 6, for each item with significant differences, values will be shown for p and r_s. Significantly different items have a p value of less than 0.05 and the r_s value shows the strength of the association between the ranks. Table 2.1 provides an interpretation for r_s values and how to determine their strength.

Table 2.1: Strength of Association for Spearman's Rho

r_s	***Interpretation of strength of correlation***
< 0.15	*very weak*
0.15 – 0.25	*Weak*
0.25 – 0.40	*Moderate*
0.40 – 0.75	*Strong*
>0.75	*very strong*

Adapted from University of Gruningen, 2016

2.7.4 Multi-Dimensional Scaling Analysis

Multi-dimensional scaling analysis was used in this study to help visualise similarities or dissimilarities between sets of data, particularly for visualising changes in the overall responses of different cohorts or individuals.

2.7.4.1 Overview

Multidimensional scaling (MDS) is a statistical analysis technique that is used to graphically display the similarities or dissimilarities between objects. MDS is capable of modelling nonlinear relationships between variables, it does not require multivariate normality, and ordinal or nominal data may be used (Jaworska & Chupetlovska-Anastasova, 2009). As such, it can be an alternative to other multivariate techniques such as cluster analysis or factor analysis, but it can also be used in conjunction with other techniques (Arce & Garling, 1989). The principal aim of this kind of analysis is to generate a configuration of points whereby the distance between these points match as close as possible to the proximities between these objects (Kruskal, 1964). See Figure 2.3 for an example of an MDS solution.

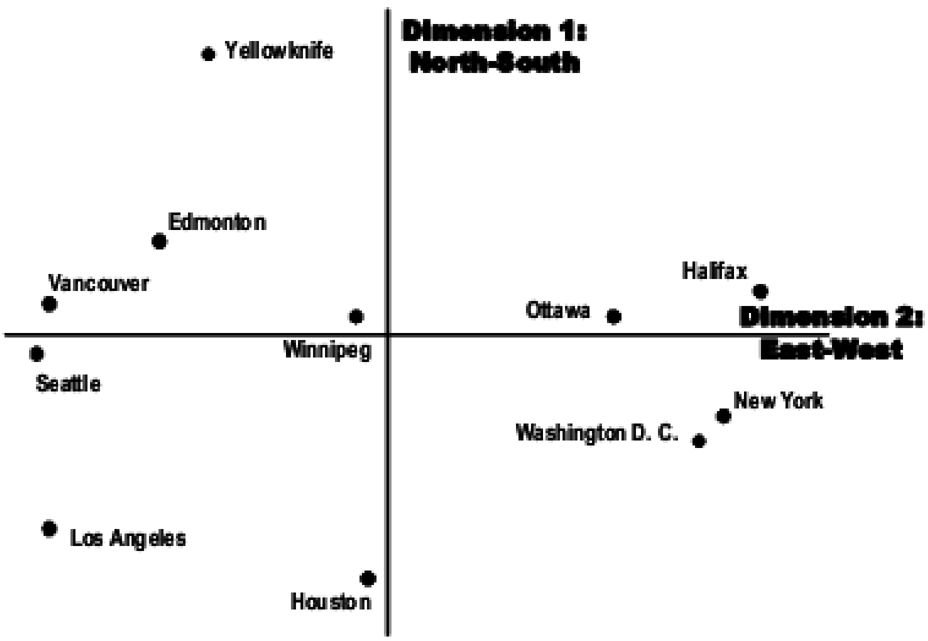


Figure 2.3: Example of an MDS solution with distances between pairs of cities

From Jaworska & Chupetlovska-Anastasova, 2009

“Dissimilarity” and “similarity” differ in terms of data for MDS analysis. In similarity scales, large numbers imply greater similarity, whereas the reverse is true for dissimilarity scales. If objects are considered to be similar, then their data points will be found near to each other on the resulting graph. The dissimilarities (δ) between objects can be computed indirectly, or collected directly. These are then optically scaled to provide a set of values referred to as “disparities”. Once the disparities have been obtained they are input into an MDS model and, following a specific type of analysis, a set of distances (*d*) is generated that may be plotted on *n* number of dimensions (Jaworska & Chupetlovska-Anastasova, 2009).

2.7.4.2 ALSCAL programme

Due to the various types of data that can be analysed by MDS, there are several different programmes that can run MDS analysis, specific to the type or nature of data involved. In this study, the ALSCAL programme was used on SPSS v21. Within the ALSCAL programme itself, there are a number of further MDS models that may be applied in numerous ways. Prior to choosing a model and form of analysis, consideration must be given to the nature of the data so as to choose an appropriate method of analysis.

Shape of the data

The ALSCAL programme is suitable for rectangular or square shaped data (Young, et al., 1978). In a rectangular matrix, the columns and rows represent different objects. In a square matrix, the rows and columns represent the same objects. Square matrices can be distinguished further into symmetric or asymmetric matrices. The dissimilarity (δ) between A and B is equal to the dissimilarity between B and A (δA = δB) in a symmetric matrix. In this matrix, only the lower triangle of the square is used in the MDS analysis due to the symmetric nature of the matrix. If the dissimilarity from A to B is not equal to the dissimilarity from B to A (δA ≠ δB) then the matrix is considered asymmetrical. The upper and lower triangles of this matrix are not symmetrical so they are both included in the MDS analysis.

Number of input matrices

The data used can consist of single or multiple matrices. If the data consists of one matrix it is referred to as “two-way”. It is called a “two-way” due to the fact that a single set of objects is paired with itself for analysis. When dealing with more than one matrix it is referred to as a “three-way”. The matrices are analysed at the same time and one plot is generated. Data with multiple matrices is often used when various different participants are analysed simultaneously, or if the same participant is studied more than once (Jaworska & Chupetlovska-Anastasova, 2009).

Number of modes

The number of modes refers to the number of variables involved in the analysis. There can be one, two, or three modes in the input matrix. In one mode data, only one variable is analysed which therefore would lead the matrix shape to be square.

Level of measurement

The data involved in the analysis can be considered as either metric or non-metric. Metric, like parametric data discussed earlier, is either interval or ratio. Non-metric data on the other hand is ordinal. Much like in the analysis of non-parametric data, in non-metric MDS only the rank order of the data is preserved instead of the numerical values.

Measurement process

The data in the input matrix can be considered as discrete or continuous. Before MDS analysis is carried out, the data is optically scaled to provide a set of val ues known as disparities (d*) so that:

$$d^*_{ijk} = \perp[\delta_{ijk}]$$

where $\perp$ is a specific transformation dependent on the measurement level and process of the data. In the analysis, the data is assumed to be categorical and if it is treated as discrete data, then the dissimilarities which are in the same category are represented by the same value following the transformation. Ordinal data which is treated as discrete (do) is transformed using the following equation:

$$\perp^{do}: (\delta_{ijk} \approx \delta_{mno}) \rightarrow (d^*_{ijk} = d^*_{mno}) \text{ and if}$$

$$\perp^{do}: (\delta_{ijk} < \delta_{mno}) \rightarrow (d^*_{ijk} \leq d^*_{mno})$$

where δ_{ijk} is the dissimilarity between *I* and *j* on matrix *k*. If the ordinal data is continuous (co), each dissimilarity within a category is denoted by a real number within an interim of real numbers such that:

$$\perp^{co}: (\delta_{ijk} \approx \delta_{mno}) \rightarrow (d^-_{ijk} = d^-_{mno}) \leq (d^*_{ijk} , d^*_{mno}) \leq (d^+_{ijk} = d^+_{mno})$$

where d^-_{ijk} and d^+_{ijk} are the lower and upper limits of the interval of possible real numbers of d^*_{ijk}.

Conditionality

The relationships that may exist among observations are referred to as conditionality. There are multiple types of conditionality, these being:

- Matrix conditional
- Row conditional
- Column conditional
- Unconditional

The conditionality puts a limit on the comparisons of dissimilarities to within the chosen condition, meaning that if there is more than one input matrix, and the data is matrix conditional, then the dissimilarities are restricted to being compared within each matrix. If the data is row conditional however, then the data in row 1 of each matric is compared with each other and the same from row 2, etc.

The default for the ASCAL programme is single, symmetric matrix of discrete data, and that is matrix conditional.

2.7.4.3 MDS Model and MDS Analysis

There is a difference between an MDS model and MDS analysis. An MDS model is an algebraic equation that creates a simple geometric representation. MDS analysis, on the other hand, is how this model is applied. MDS models themselves can be considered weighted or unweighted. Unweighted models are the most basic, whilst the weighted model takes individuals' perception and cognitive processes into account. Essentially, each subject may weigh various aspects differently (Jaworska & Chupetlovska-Anastasova, 2009). ALSCAL uses three unweighted MDS models, each of these are variations of the Minkowski model:

$$d^{p}_{ij} = \sum_{a}^{r} \left| x_{ia} - x_{ja} \right|^{p} \qquad (p \geq 1) \text{ and } x_i \neq x_j$$

where d_{ij} is the distance between i and j, x_{ia} is the co-ordinates of point i on plane a, p is the Minkowski exponent and r is the number of dimensions. The number of dimensions most often used in the ALSCAL programme are 2 or 3, but the number of possible dimensions ranges from 1 to 6.

If p is varied, which is the Minkowski exponent, the model used changes. The Minkowski exponent cannot equal less than 1. When p equals 2, it is called the Euclidean distance model, and this is the default model used by the ALSCAL programme. This model is typically used when the user knows little about the process that created the disparities (Jaworska & Chupetlovska-Anastasova, 2009). The Euclidean distance model in 2 dimensions (r = 2) is represented by:

$$d^2_{ij} = \sum_{a}^{2} \left| x_{ia} - x_{ja} \right|^2$$

Here, the distance, d_{ij}, is defined as the square root of the sum of squared differences between co-ordinates.

Types of MDS Analysis

Based on the unweighted Minkowski model, four types of analysis have been identified. They are classified according to the nature of the input data. These are:

- Classical multidimensional scaling (CMDS)
- Classical multidimensional unfolding (CMDU)
- Replicated multidimensional scaling (RMDS)
- Replicated multidimensional unfolding (RMDU)

The most basic form of MDS is CMDS and it manages single matrices of square, symmetric data that are matrix conditional. RMDS is typically matrix conditional and can be used to analyse multiple subjects at the same time creating a single plot. One advantage of using RMDS instead of carrying out multiple CMDS analysis is that regularly an interaction might become apparent that would not have been observed from multiple CMDS plots (Jaworska & Chupetlovska-Anastasova, 2009). CMDU, alternatively, manages one matrix of rectangular data that is row conditional. Here, stimuli and subjects are represented by two sets of points that present the dissimilarities as much as possible. Where CMDU manages one matrix, RMDU analyses several matrices of rectangular data as the same time. Comparisons of these types of analysis can be found in Table 2.2.

Table 2.2: Types of MDS analysis available within the ALSCAL programme on SPSS V.19

Analysis	Shape	No. of Matrices	Condition
CMDS	Square	1	Matrix
CMDU	Rectangle	1	Row
RMDS	Square	2	Matrix
RMDU	Rectangle	2	Row

Additional forms of MDS analysis are available that are suitable for asymmetrical and weighted data, such as weighted multidimensional scaling (WMDS), which is also known as individual differences MDS (INDSCAL), ALSCAL and AINDS.

2.7.4.4 MDS Used in this Study

Classical MDS analysis was applied to the data generated from the PSTs' responses to the pre- and post- questionnaires. The Euclidean distance model was used and the configuration was plotted in 2 dimensions. The dissimilarities were computed as Euclidean distances indirectly, in which the rows represented participants, and columns represented responses to the items in the questionnaires. The resulting input matrix of dissimilarities was symmetrical so that both the rows and columns represent the respondents. In CMDS the data undergoes a number of steps:

1. The scaled disparities are denoted by randomly assigned points on a plane.
2. The points are then computed to fit the appropriate model so that the inter-point distances represent the data fairly. As discussed previously, non-metric CMDS only preserves the rank order of the data, and not the numerical values.
3. Young's stress is measured to determine the variance between the dissimilarities and the configuration distances. This is a measure of how well the configuration itself fits the experimental data. The stress is measured across the range of 0 to 1, where the lower the stress value, the better the fit.
4. The configuration finally undergoes an iterative process that re-plots the co-ordinates so as to obtain an improved stress value. This process is repeated for

a maximum of 30 iterations, or until the improvement is less than 0.001. These are the default settings on the ALSCAL programme.

2.7.4.5 Interpretation

When interpreting an MDS image, there are two things to look for: clusters and dimensions. Clusters are groups of items that appear to be closer to each other than to other items within the image. For example, in an MDS map of perceived similarities among animals, it could be found that farm animals such as pigs, cows, and chickens are located very near each other, forming a cluster. Elsewhere on the graph a cluster of animals typically found in a zoo such as lions, tigers and elephants could be observed. When a cluster is observed within an MDS map it is important not to place too much weight on whether item *x* in the cluster is slightly closer to item *y* or item *z* in the cluster. The exact position of items within a tight cluster has minimal impact on the overall stress and so placement may be quite random.

Dimensions refer to specific attributes of items that appear to place the order of the items in the MDS map along a continuum. An example of this would be an MDS map of the perceived similarities of breeds of dogs. Within that map there may be a clear ordering of dog breeds based on their size going from bottom to top, right to left, diagonally at any angle, etc. across the MDS image. Within the same image, another ordering of dogs could be seen according to how vicious they are (Kruskal & Wish, 1978; Analytictech, 2016)

Within this thesis, MDS is used to graphically display the similarities between groups of participants, and their similarities to the most desirable response of a participant. The most desirable or “Ideal” or “Max” response is the most positive response to each item that a participant could have provided. The “Ideal” or “Max” for a set of items is shown in many of the MDS maps in this thesis so that it would be quite clear to see whether individual participants or specific groups are responding similarly to the ideal set of responses or max possible score. Additionally, it is used to show movement towards or away from the most positive response following TEPs.

2.7.4.6 K-Means

The aim of k-means analysis is to cluster a set of observations into k clusters in which each observation has been classified and belongs to the cluster, with the nearest mean (or centroid) (Kanungo, et al., 2002). Clusters are obtained using the following process:

1. First, K points are placed into the space represented by the objects that are to be clustered. These points represent the initial group centroids.
2. Each object is then assigned to the group with the closest centroid.
3. Once each of the objects has been classified into a group, the positions of the K centroids are recalculated.
4. Steps 2 and 3 are repeated until the centroids no longer move. This process provides a separation of the objects into groups (Politecnico Milano, 2016).

K-means clustering is used in this thesis in addition to MDS analysis to examine the similarities between groupings. The values input for MDS analysis are also input into k-means analysis to more accurately determine clusters which appear within the MDS maps.

2.8 Conclusions

This study consisted three main phases. Quantitative research was the methodology used for phases 1 and 2 to analyse data from PSTs across Europe. A case study approach was employed for phase 3 to examine a particular cohort of PSTs. The statistical analysis described in this chapter has been used to analyse the data in Chapters 3, 4 and 6. The analysis was carried out primarily to determine changes of participants' responses over the course of TEPs and differences between different groups of participants such as those with different experience level or teaching experience. MDS was used to help visualise similarities or dissimilarities between sets of data, particularly for visualising changes in the overall responses of different cohorts or individuals.

There are limitations to the approaches adopted within this study. The quantitative approach used is based on self-completed questionnaires which rely on the honesty of respondents. While time was always given to the completion of questionnaires, it could be hurriedly completed. Additionally, the questionnaires were only given to participants who took part in the TEPs and therefore it was a self-selecting group which is not necessarily a representative sample. In phase 3 the sample size was not large enough to do full statistical testing, such as factor analysis.

Additional details relating to analysis are given as relevant within the results section of the following Chapters. Phase 1 and phase 2 studies are now discussed in Chapters 3 and 4 respectively.

Chapter 3 – European Comparison of Pre-Service Teachers' Understanding and Views of Inquiry

IBSE has been shown to be an effective pedagogy for teaching science (Section 1.1.3). During initial teacher education, PSTs need to be prepared in such a way that they are confident and competent with inquiry instruction. It has been show that TEPs where teachers are immersed in authentic inquiry will more likely enhance teacher knowledge, prepare teachers to implement inquiry instruction, and lead to enhanced student understanding (Capps & Crawford, 2009).

Following the implementation of the ESTABLISH inquiry TEPs, there was an opportunity to analyse a set of data which could be used to address the first phase of this study which is:

- Determination of PSTs' understanding and views of inquiry practices, and how this changes following an inquiry teacher education programme.

The ESTABLISH data allows for analysis of the understanding of and views towards inquiry that PSTs hold already and this relates to their views of what "good" science teachers do in their classrooms. PSTs' self-efficacy in the inquiry classroom and how open they are to changing their practices was also investigated using ESTABLISH data. Another aspect included in the ESTABLISH data are PST's general views towards science and their relationships to science outside of the classroom. The data available allows for analysis of an Irish sample of pre-service teachers, and also a wider sample of PSTs from across Europe.

3.1 ESTABLISH project

The ESTABLISH project, which has been discussed in Section 2.3, was set up to support pre-service and in-service teachers across Europe in adopting inquiry based approaches in their classroom practice.

The ESTABLISH teacher education programmes for in-service teachers, as outlined in ESTABLISH documents (ESTABLISH, 2014), were developed with a set of minimum criteria which were to be included in the programmes. The criteria were:

- A minimum of 10 hours contact time;
- Training carried out over a minimum of 3 stages;
- It was strongly encouraged that the materials be trialled in real classrooms;
- A minimum of two teachers from each school were recommended to attend;
- It was recommended that the workshops be held in schools as much as possible;
- It was suggested that a workshop take place in a relevant industrial setting.

This set of criteria was agreed upon for in-service teachers, but this was not possible in the majority of instances for PSTs due to their already existing timetables. As such, it was recommended that ESTABLISH materials be included in PST workshops, but it was recognised that it would be necessary to adapt these criteria and materials to suit existing national programmes.

In addition to the criteria for how the programmes should run, a framework consisting of four core elements was developed that was to be included in all of the TEPs. Each partner group implemented each of these core elements in both their in-service and pre-service TEPs. ESTABLISH material that was developed for the in-service teacher programme was available for use with existing national PST programmes.

The first core element was the ESTABLISH view of IBSE. It was important that the participants developed an understanding of inquiry. Key ideas here were the definition and rationale for inquiry, how it could be used, and what skills might be developed in the teaching process. Each partner implemented this in the way that was most suitable for their country, e.g. teachers experiencing inquiry as students or teachers given short lectures on inquiry.

The second element included within the core framework is industrial content knowledge (ICK). The main reason for including ICK is to give young people an opportunity to meet professionals who work with science and technology in industry and research so that the students can widen their knowledge about fields where those who have studied science and technology work, how they work and how they contribute to society. Additionally, ICK provides a context for science so that students can see its purpose and value in everyday life.

The third core element included was teacher as implementer. The key aspects of this element were included to help teachers prepare for successful implementation of IBSE activities, and to identify and meet the associated challenges. The aspects which were to be included was training in order to practice the application of IBSE and to reflect on how to encourage communication within the classroom, the identification of IBSE links with the curriculum, and support and scaffolding for students and teachers.

The final core element was teacher as developer. This element was aimed at developing the teachers' abilities to develop IBSE practice which is at an appropriate level for their students and to modify their own materials to include inquiry. To be a developer of inquiry material it was deemed necessary to first be a successful implementer as a teacher would then have gained the ability and confidence to modify material towards inquiry. The ESTABLISH group recognised that a developer might go through stages of experience where first they adapt material until they then develop their own original material.

Supplementary to this, there were four additional supporting elements that could also be implemented, depending on the needs of the teachers involved or on the local situation of the TEP itself. Unlike the core elements, all of these elements did not need to be incorporated into each programme (ESTABLISH, 2014). These elements can be seen in Figure 3.1. The additional elements were suggested in ESTABLISH for countries who were already experienced in inquiry or who wanted to add further specialist topics, e.g. appropriate use of ICT in inquiry classroom or developing skills of argumentation in the classroom (see Figure 3.1).

These elements were based on the main obstacles that teachers face in implementing IBSE in their classrooms, as discussed in Chapter 1. The primary challenge faced by teachers is their limited understanding of inquiry. Teachers may fail to understand fully the concept of inquiry and particularly how to implement it effectively in the classroom (Crawford, 2000).

Teachers often believe that inquiry takes up too much time and as a result may struggle to cover the curriculum (Anderson, 2007; Lehman, et al., 2006). Experiencing authentic inquiry as part of TEP has been show to prepare teachers to implement inquiry instruction (Capps & Crawford, 2009). This explains the focus on Core Elements 1 and 3. Additionally if they are able to adapt their own materials to inquiry based materials, then they are competent in the pedagogy and the practice, hence Core Element 4.

Figure 3.1 Core and Supplementary Elements of the ESTABLISH programmes
(Ottendar & Ekborg, 2014)

Industrial content knowledge (ICK) was a term coined to encompass the links between school science and everyday science which may make science more interesting to the students. Core Element 2 was a focus of the programmes and it was aimed at developing knowledge about scientists and engineers who are people who have interesting and important jobs.

3.1.1 Irish Pre-service Programme

The Irish programme for PST was directed primarily towards 2nd year students who would go on to be teachers of physics and/ or chemistry, and physical education and biology. These participants had completed the same educational theory and science teaching methodology modules, but their science content backgrounds are different. All of these PST had completed three weeks of teaching practice in schools. The remainder of the Irish cohort were 3rd year students who would go on to be teachers of physics, and/or chemistry. These participants had completed additional science methodology and science content modules than those in 2nd year, however, they also only had three weeks of teaching experience and as such had a very similar background to those in 2nd year.

The pre-service programme was not given in the form of specific workshops. The approach taken was to incorporate the ESTABLISH approach and elements of IBSE into regular science courses where the students could learn science by inquiry. The 2nd years carried out four three-hour laboratory sessions on the topic of sound. The 3rd years carried out four three-hour laboratory sessions on the topic of “exploring holes”. Exploring holes was a topic developed around the theme of ‘holes’ and the concept that not all holes are visible to the naked eye. In this topic, the links between chemical structure, properties and use are highlighted. Exploring holes can also be used to address the representation of different materials at the macro, sub-micro and symbolic levels. Over the course of the unit, various materials were tested to determine if they could be effectively used as filters, and thus have holes (Establish, 2014). What was important about the Sound and Exploring Holes units is that they were contexts that the PSTs were not experts in. The participants were learning a topic of science for the first time through the context of inquiry, much like the students they may eventually teach. The programme is discussed in the ESTABLISH report “D4.6” on effective models for in-service and pre-service science teacher training in IBSE (Ottendar & Ekborg, 2014).

3.2 Sample, Data & Analysis

All of the countries involved in ESTABLISH who ran PST workshops distributed ESTABLISH I Pre questionnaires (see Appendix A.1) to the PSTs and at the end of the workshops, ESTABLISH Post questionnaires (see Appendix A.2) were distributed.

As discussed in Section 2.4, the individual questions in the questionnaire were grouped into similarly themed questions and the data were analysed under these headings. These topic groups are:

- Understanding of inquiry
- Views towards inquiry in the classroom
- Views of “good” teachers of science
    - Pedagogy
    - Development of content knowledge
- Self-efficacy in the inquiry classroom
- Views to science outside of the classroom

367 PSTs from 8 institutions in seven countries across Europe completed the pre questionnaire. 75% of the participants in this study were 25 years old or less, 65% were female, and 76% only had between 0 and 20 weeks teaching experience.

The participants were asked to self-rate their own experience with inquiry and 59% said that they were beginners with inquiry based science education (BE), 33% said that they have some experience with inquiry (SE), and 1% said that they are very experienced with inquiry (VE). The remaining percentage did not indicate their experience with inquiry. A summary table of participants can be found in Table 3.1.

In the next section, the data will be analysed according to the themes given above. Most of the analysis involved the whole dataset, whereas analysis of any changes was conducted on a matched data set. MDS is analysed as described in Section 2.7.4.5. Both sets of questionnaires (pre- and post-) were completed by 217 PSTs which accounts for 59% of the original group. This subset of participants includes a very similar profile of PST in terms of age, gender, and experience with inquiry as the overall cohort.

Table 3.1: Overview of PST cohorts that have completed ESTABLISH questionnaires

Code	Number of Teachers	Age range %*					Weeks teaching %*						Gender %*		Experience with IBSE %*			Matched Pre & Post
		18-20	21-25	26-30	31-35	36+	0-20	21-40	41-60	61-80	81-100	101+	M	F	BE	SE	VE	
H	25	-	-	-	-	-	-	-	-	-	-	-	68	32	-	-	-	0
B	48	-	88	13	-	-	92	4	-	-	-	-	29	71	83	17	-	90
A - Ireland	83	74	12	2	-	-	100	-	-	-	-	-	54	46	37	61	-	40
J	50	4	74	18	4	-	38	-	-	-	-	-	24	76	60	38	-	52
D	59	2	98	-	-	-	98	-	-	-	-	-	10	90	93	7	-	56
K	26	8	69	23	-	-	77	-	-	-	-	4	58	42	54	42	4	23
C	40	3	25	28	23	20	44	46	5	-	-	2	43	58	93	5	3	100
E	36	-	92	8	-	-	100	-	-	-	-	-	8	92	28	69	-	100
Total	367	18	57	10	3	2	76	6	1	-	-	0.3	35	65	59	33	1	59

*Balance relates to percentage of non-respondents.

BE, SE, VE = beginners, some experienced and very experienced with inquiry

3.3 Results and Discussion

Following the implementation of the ESTABLISH inquiry TEPs, there was an opportunity to analyse a set of data which could be used to address the first phase of the study which is "determination of PSTs' understanding and views of inquiry practices, and how this changes following an inquiry teacher education programme".

This section discusses the results of the analysis in terms of PSTs understanding of and views towards inquiry, self-efficacy in the inquiry classroom, views of good teachers, and views towards science outside the classroom.

3.3.1 Understanding of Inquiry

PSTs overall understanding of inquiry is determined from their responses to questions asking them to rate their understanding of IBSE, as well as their understanding of the role of a teacher and the role of the students in the inquiry classroom. Results are shown in Table 3.2. Overall, it is clear that the majority of PSTs across Europe have some understanding of inquiry, particularly the role of students in the classroom.

The PSTs self-rated themselves in terms of their experience with inquiry. There may be some variation between country cohorts which could be accountable by the difference in levels of experience with inquiry of the individual teachers within each country cohort. The individual response to each question, based on their level of experience, is shown in Figure 3.2.

For each item in this grouping, the SE group indicate a significantly greater understanding of inquiry than the BE group (See Appendix B: Table B.2). Differences between the responses can be seen in Figure 3.2 and significantly different items are indicated with a star (i.e. significant difference between BE and SE group for this item). Analysis of the PSTs' responses was conducted to determine if there were any differences between the Irish respondents and other participants across Europe. Interestingly, there are no significant differences on any of the understanding of inquiry items.

Table 3.2: PST Initial / Final Understanding of Inquiry

	Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree	Spearman's Correlation With Q17 Initially		Significant Changes (WSR) – BE group		Spearman's Correlation With Q17 Finally	
						r_s	P	Z	P	r_s	p
11. I don't fully understand inquiry based science education	16.6%	44.7%	17.2%	10.1%	4.1%	.206	.000	-4.377	.000	.328	.000
12. I don't fully understand my role as a teacher in an inquiry classroom	17.7%	46.9%	14.2%	10.9%	3.0%	.201	.000	-4.716	.000	.296	.000
13. I don't fully understand the role of the students in an inquiry classroom	21.8%	48.0%	14.2%	7.1%	1.9%	.144	.008	-4.031	.000	.225	.001
17. Inquiry will never be my main teaching method	13.6%	27.0%	36.0%	12.0%	4.4%	N/A	N/A	_	_	N/A	N/A

*See Section 2.7.3 for explanation of Spearman's correlation and Section 2.7.2 for explanation of Wilcoxon Signed Rank (WSR)

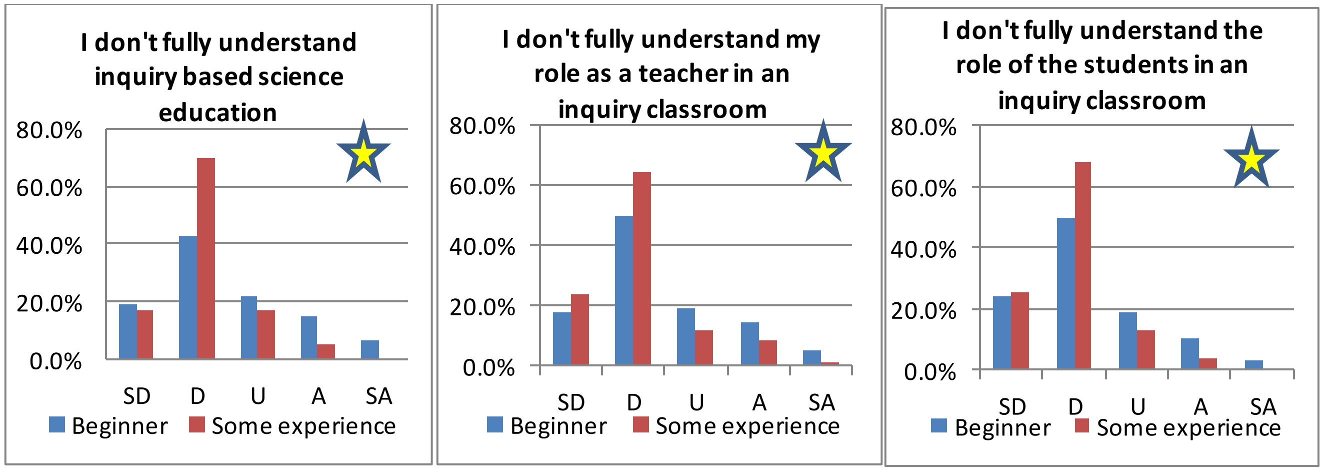


Figure 3.2: PST Initial Understanding of Inquiry, based on experience level

(SD, D, U, A, SA = strongly disagree, disagree, uncertain, agree and strongly agree; Balance to 100% relates to percentage of non-respondents)

Following the TEP, the overall cohort significantly increased understanding of inquiry. This change is evident in the MDS analysis, for each country cohort, represented by a specific letter (Table 3.1), mapped relative to an 'ideal' response (Figure 3.3). The 'ideal' response is that of fully understanding IBSE and the roles of teacher and student in an inquiry classroom. The asterisk denotes the position of a cohort following the TEP.

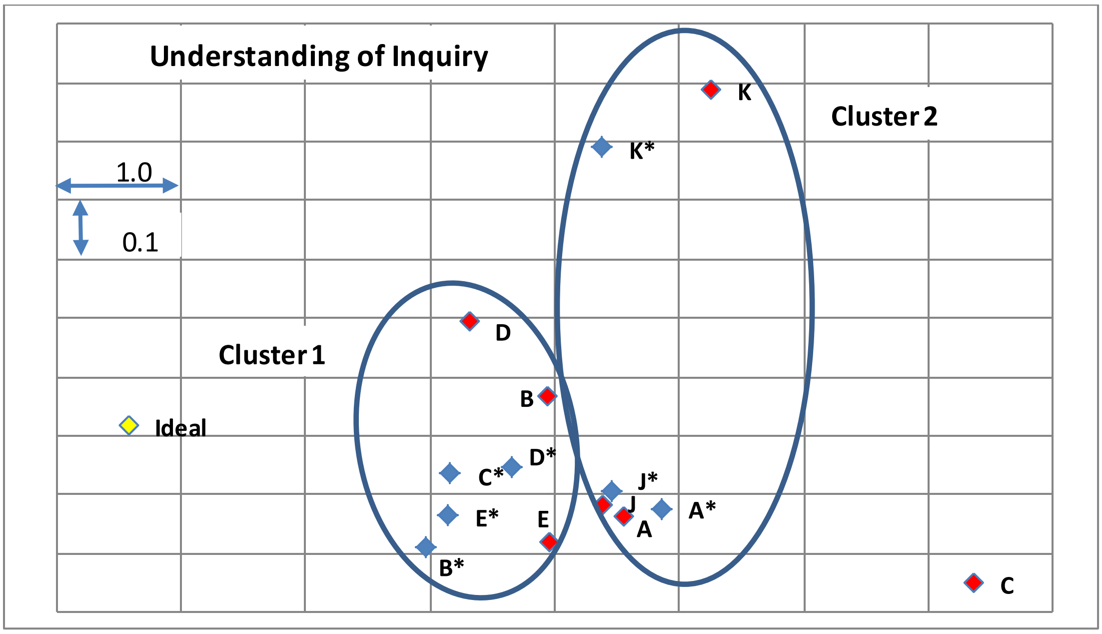


Figure 3.3: Changes in Understanding of Inquiry – MDS Analysis
(Each letter refers to a specific country cohort. * denotes responses after TEP)

The shifts evident in Figure 3.3 are primarily as a result of changes in the BE group as they understood inquiry significantly more following the TEP. Those with SE did not change significantly following the TEP (Table 3.2).

There is a variation in responses as to whether "inquiry will never be my main teaching method" (Table 3.2) and when responses are correlated with the understanding of inquiry questions there are weak, but significant positive correlations both initially and finally. The greater their understanding of inquiry, the more they would consider inquiry as their main teaching method in future. This suggests that increasing PSTs' understanding of inquiry may increase the likeliness of them using inquiry as their main teaching method in future.

The Irish PSTs agreed significantly more that inquiry will never be their main teaching method following the TEP (Appendix B: Table B.15). This suggests that some changes need to be made to the Irish TEP.

3.3.2 Views towards inquiry

Barriers to implementing inquiry practices in the classroom have been noted from the literature and discussed in Chapter 1, including lack of classroom time which can impact on achieving curriculum aims (Anderson, 2007). PSTs' level of agreement to the 5 statements shown in Table 3.3 were noted and responses for BE and SE are shown in Figure 3.4.

Approximately half of the group agree that inquiry is suitable for achieving the aims of the curriculum even though they are uncertain about whether it will be easy to teach the curriculum. Almost 60% believe that it is suitable for students of varying capabilities, and that students do not need to know a lot of facts before they can participate in inquiry activities. The PSTs are quite uncertain however about whether inquiry takes up too much time to implement.

Prior to the TEP there were significant differences in responses on two items depending on the experience levels of the participants. The SE group were more likely to agree than the BE group that inquiry is appropriate for achieving the aims of the curriculum and that it would be easy to teach the curriculum using inquiry. These differences can be seen in Figure 3.4 (significantly different items are indicated with a star) and Appendix B: Table B.3.

When it comes to the differences between the views of the teachers towards inquiry based on country, the Irish participants are less likely to believe that students need to know a lot of facts prior to participating in an inquiry activity, but they are more likely to agree that inquiry is only suitable for very capable students (Appendix B: Table B.9).

Table 3.3: PST Initial / Final Views towards inquiry

	Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree	Significant Changes (WSR) – whole group		Significant Changes (WSR) – BE group	
						Z	P	Z	P
14. I think inquiry takes up too much classroom time for me to implement	8.4%	28.9%	30.0%	23.4%	4.9%	-	-	-2.709	.007
15. The use of inquiry is appropriate to achieving the aims of the curriculum	1.4%	7.9%	25.6%	44.4%	10.9%	-	-	-	-
16. Inquiry based teaching is only suitable for very capable students	18.3%	41.4%	22.9%	11.7%	2.5%	-2.267	.023	-	-
25. It would be easy to teach the curriculum using inquiry based methods	5.4%	22.1%	43.6%	17.2%	1.9%	N/A	N/A	N/A	N/A
31. Students need to know a lot of facts before they can participants in inquiry activities	11.4%	45.0%	24.0%	14.4%	1.4%	N/A	N/A	N/A	N/A

*See Section 2.7.2 for explanation of Wilcoxon Signed Rank (WSR)

Figure 3.4: PST Initial Views towards Inquiry, based on experience level
(SD, D, U, A, SA = strongly disagree, disagree, uncertain, agree and strongly agree; Balance to 100% relates to percentage of non-respondents)

In the Final questionnaire, the PSTs were not asked questions 25 and 31 (Table 3.3), but the responses to questions 14, 15 and 16 were matched. Following the TEP, the group are more sure that inquiry is suitable for all students (Table 3.3) while the BE group now significantly disagree that inquiry takes up too much time in the classroom to implement. Overall changes in views towards inquiry by matched pairs of teachers are depicted by MDS shown in Figure 3.5, showing movement towards the Ideal position.

With more experience of inquiry teaching, the BE group are now more sure that inquiry is appropriate for the aims of the curriculum and that it's possible to teach through inquiry methods.

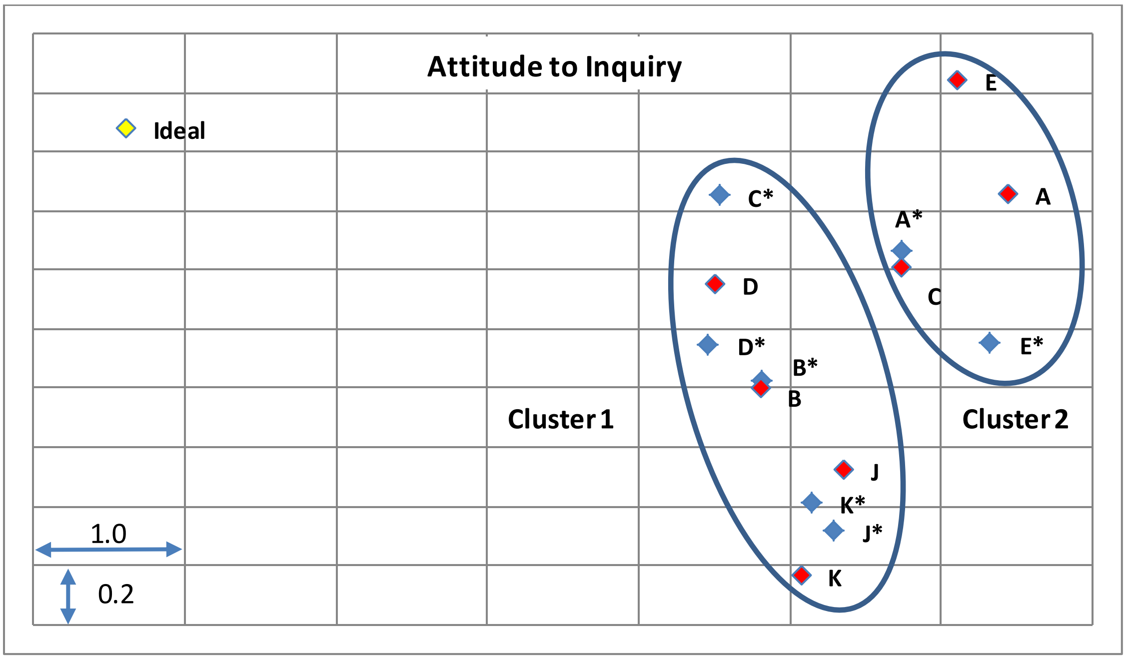


Figure 3.5: Changes in Views towards Inquiry – MDS Analysis
(Each letter refers to a specific country cohort. * denotes responses after TEP)

3.3.3 Self-Efficacy in inquiry classroom

When teachers know little about a particular area of science they are unconfident delving into it in their class, and they believed their students' learning would be inhibited without their constant guidance and influence (Lotter, et al., 2007; Zion, et al., 2007). PSTs' self-efficacy and comfort in the inquiry classroom demonstrates how they think about themselves within the context of teaching in the inquiry classroom.

As the group are PSTs, it is understandable that approximately 50% of them are not yet comfortable with classroom management or asking higher order questions (Table 3.4). The BE PSTs are more uncomfortable with teaching areas of science that they have a limited knowledge of when compared to the SE PST (Figure 3.6, and Appendix B: Table B.4).

Table 3.4: PST Initial / Final Self-efficacy in the inquiry classroom

	Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree	Spearman's Correlation With Q45 Initially		Significant Changes (WSR) – SE group	
						r_s	P	Z	P
43. I would find it difficult to manage a classroom where each student is doing different activities	6.0%	31.3%	22.1%	30.8%	3.3%	-	-	-	-
44. I am unsure how to ask students higher order questions that promotes thinking	7.1%	39.0%	19.9%	29.2%	0.8%	-.196	.000	-1.991	.046
46. I am uncomfortable with teaching areas of science that I have limited knowledge of	2.7%	12.0%	8.7%	52.0%	16.1%	-	-	-	-
48. I would be uncomfortable with asking questions, in my class, where I am unsure of the answer myself	3.5%	8.7%	8.2%	50.4%	21.5%	-.217	.000	-	-
45. I have sufficient knowledge of science to implement an inquiry lesson effectively	3.5%	16.3%	36.8%	35.4%	3.5%	N/A	N/A	-	-

*See Section 2.7.3 for explanation of Spearman's correlation and Section 2.7.2 for explanation of Wilcoxon Signed Rank (WSR)

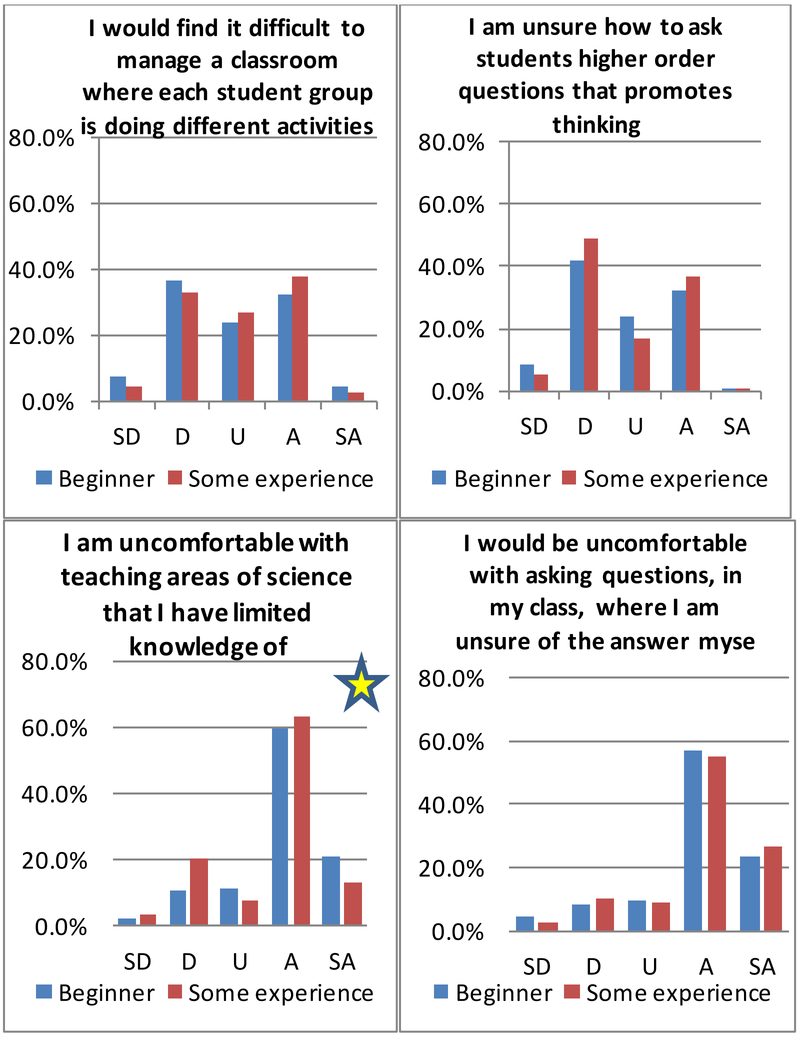


Figure 3.6: PST Initial Self-efficacy in the inquiry classroom, based on experience level (SD, D, U, A, SA = strongly disagree, disagree, uncertain, agree and strongly agree; Balance to 100% relates to percentage of non-respondents)

The majority of the group feel that they have insufficient knowledge of science at this stage to implement an inquiry lesson effectively, and they are also uncomfortable teaching areas of science that they are not familiar with or asking questions where they are unsure of the answers themselves.

If a participant agreed they had sufficient knowledge of science to implement an inquiry lesson effectively, they were more likely to know how to ask students higher order questions that promote thinking and be comfortable with asking questions that they did not know the answer to themselves. Interestingly, asking students questions where they do not have the answer themselves is a factor that makes nearly a quarter of the group very uncomfortable. This is an area where PSTs need to develop skills in their reasoning and thinking teaching strategies.

Confidence in these areas is likely to be only achieved with time (and probably experience in the classroom). Therefore over the short period of the ESTABLISH workshops, only one change was significant in that they were more sure of asking higher order questions. This change was primarily as a result of the SE group who changed significantly, while the BE group were unchanged (Table 3.4). MDS data is rather clumped, showing that only small changes were achieved (Figure 3.7).

Figure 3.7: Changes in Self-efficacy in the inquiry classroom – MDS Analysis
(Each letter refers to a specific country cohort ; * denotes responses after TEP)

Prior to the TEP, the PSTs were not comfortable with certain practices in the inquiry classroom. However, PSTs are very open about changing their methodologies, even if they are very happy with their current teaching methods. This really indicates that PSTs need to be exposed to different pedagogies as a PST, when they are open to trying various methodologies (Table 3.5). The SE participants were significantly more open to trying different methodologies in their classroom which can be seen in Figure 3.8 (and Appendix B, Table B.5).

Table 3.5: PST Initial openness to change

	Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree
34. I am happy with my current teaching methods	1.3%	8.7%	41.9%	25.8%	6.5%
35. I am open to trying different methodologies in my teaching	0.0%	0.8%	4.4%	45.2%	39.0%
36. I feel apprehensive about changing my current teaching practice	22.9%	37.1%	15.8%	6.1%	0.6%

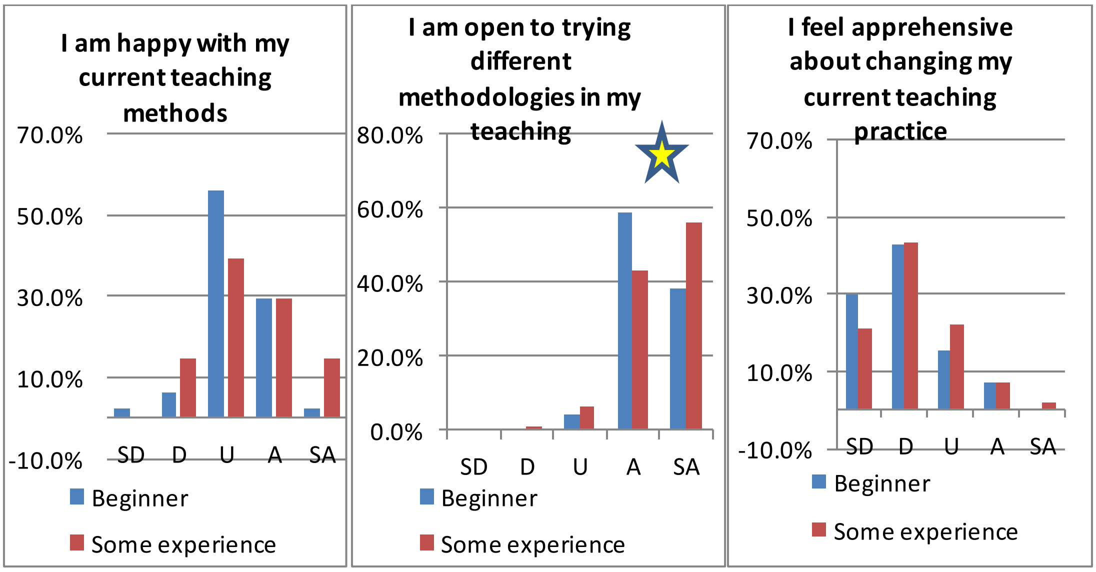


Figure 3.8: PST Initial openness to change, based on experience level
(*SD, D, U, A, SA = strongly disagree, disagree, uncertain, agree and strongly agree; Balance to 100% relates to percentage of non-respondents)

The Irish PSTs' self-efficacy in the inquiry classroom varies from the European PSTs in three areas. The Irish cohort are more sure how to ask higher order questions and are more comfortable teaching areas of science that they have limited knowledge of, but they find it more difficult to manage a classroom where all of their groups of students are doing different activities (Appendix B: Table B.10). However, the Irish PSTs are significantly more apprehensive than the European group in changing their current teaching methods (Appendix B: Table B.11).

3.3.4 Views of Good Teaching

Inquiry is not a methodology based solely on the content knowledge outcomes that can be achieved by students. The process itself is considered valuable in an inquiry lesson. If a PST places greater value on either content or process as an outcome then this may explain their views towards inquiry.

PSTs agree that developing content knowledge is not more important than developing the thinking and reasoning processes of their students. However, approximately 35% agreed that their goal was to transfer factual knowledge, while a further 35% disagreed with this statement while the remainder were uncertain. A similar proportion of PSTs agree that scientific knowledge is primarily focussed on knowing facts (Appendix B: Table B.6). This dichotomy between thinking and reasoning processes and factual knowledge is an area for further analysis. This relates to Section 3.2.3, where PSTs need to develop skills in their reasoning and thinking teaching strategies.

PSTs develop views of what a good teacher does and what their goals of teaching are. These ideas can influence their views towards inquiry or their interactions with TEPs if their views do not align with the goals or practices of inquiry instruction. Their views of good teachers are discussed further under two themes: the pedagogies teachers choose and the content teachers include.

The responses of the PSTs to inquiry pedagogies of asking higher order questions, using students' questions to guide their teaching, and allowing students to develop their own investigations, are all very positive (Table 3.6). The question relating good teachers to presenting facts and explaining them could be somewhat ambiguous as interesting facts could be presented as a starting point of a lesson but the mode of explanation may be varied.

A general point that is somewhat worrying is that nearly 40% of the PST cohort disagree or are uncertain that good teachers ask higher order questions! This again contradicts with their views of developing thinking and reasoning. It is clear that the PSTs are developing their views on science teaching but without the experience in the classroom, their views of good teaching may be very diverse.

In terms of content, the majority of the PSTs believe that good teachers do not focus solely on curriculum content, but encourage discussion on scientific topics, they show students the relevance of science in industry, and help them to understand the importance of science and technology for our society (Table 3.6).

Table 3.6: PST Initial Responses to Good Teaching

Good teaching – Pedagogies	Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree
26. Good teachers ask higher order questions	7.4%	19.1%	12.3%	43.1%	14.2%
28. Good teachers use student questions to guide their teaching	0.5%	4.9%	12.8%	60.5%	18.5%
29. Good teachers present facts and then explain them	6.5%	34.6%	24.8%	25.3%	6.0%
30. Good teachers allow students to develop their own investigation/ research questions	0.3%	1.9%	9.5%	57.8%	28.1%
Good teaching - Content	**Strongly Disagree**	**Disagree**	**Uncertain**	**Agree**	**Strongly Agree**
27. Good teachers focus on curriculum content only	37.3%	46.9%	7.4%	4.9%	0.5%
33. Good teachers encourage student discussion on scientific topics relevant to everyday life	0.5%	2.7%	3.0%	48.2%	43.1%
39. Good teachers show students the relevance of science in industry	0.0%	5.4%	14.7%	49.9%	20.2%
40. Good teachers help students understand the importance of science and technology for our society	0.8%	2.7%	5.7%	52.6%	34.9%

Interestingly, the only difference between the responses of the PSTs from the different experience levels is that although those with more inquiry experience (SE) disagree that good teachers focus on curriculum content only, those with less experience (BE) are more likely to strongly disagree (Figure 3.9, Appendix B: Table B.7).

Irish PSTs believe that good teachers ask higher order questions and show the relevance of science in industry more than their European peers. They also believe more strongly that good teachers focus on curriculum content only and present facts and then explain them (Appendix B: Table B.12).

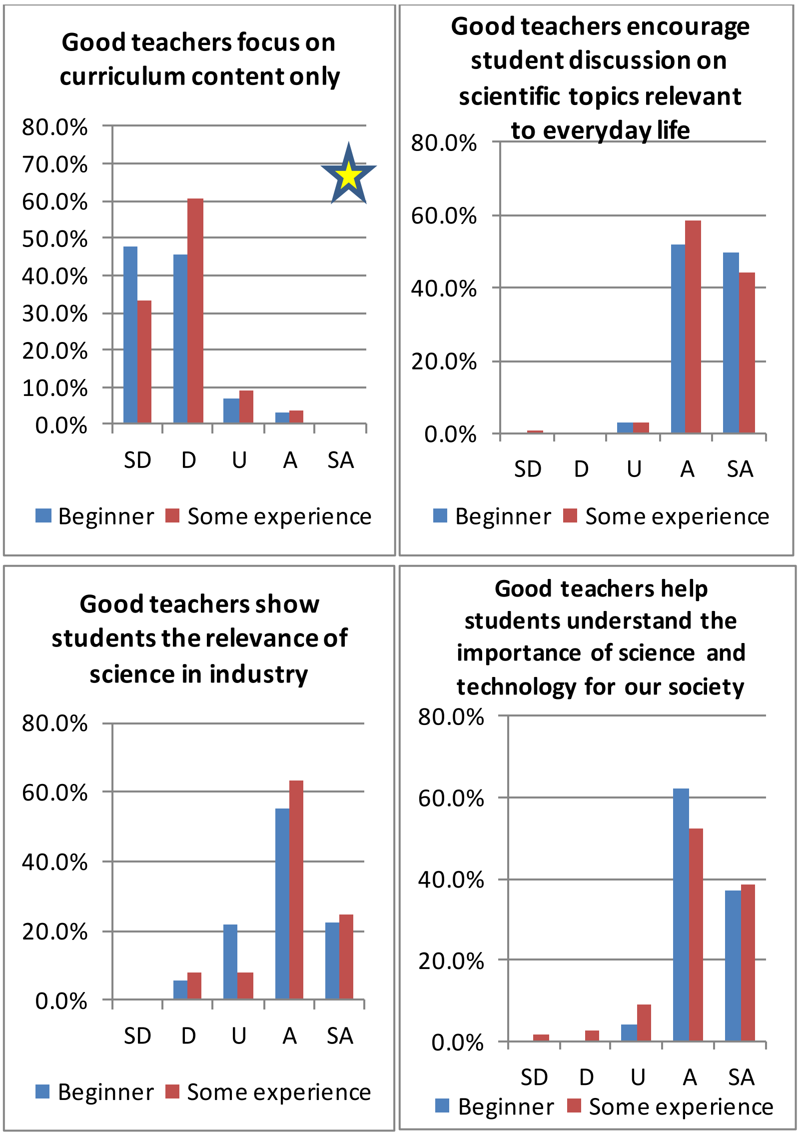


Figure 3.9: PST Initial views of Good teaching - content, based on experience level
(*SD, D, U, A, SA = strongly disagree, disagree, uncertain, agree and strongly agree;
Balance to 100% relates to percentage of non-respondents)

3.3.5 Views of science

An ability or desire to link scientific content with science beyond the classroom is valuable in an inquiry lesson. As one element of the ESTABLISH project was to focus on ICK, it is interesting to note that the PSTs want their students to know more about developments in science and engineering and they would use information about industrial processes in their teaching. However, the PSTs were uncertain about whether they can easily relate scientific content knowledge from the curriculum to these phenomena that occur outside of the classroom (Table 3.7).

Therefore this is an area that needs to be addressed by incorporating this practice into future TEPs.

Table 3.7: PST views of Science outside the classroom

	Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree
37. I want my students to know about the latest developments and applications of science and engineering	1.5%	5.0%	15.7%	55.2%	20.2%
38. I can easily relate scientific concepts in the curriculum to phenomena beyond the classroom	0.6%	10.7%	35.2%	42.1%	8.4%
41. If I had more information about industrial processes, I would use it in my teaching	1.5%	9.2%	27.6%	43.0%	16.3%

The SE group are significantly more likely to agree that they would teach about industrial processes if they had more information than the BE group. Assistance should be provided so participants feel they have the knowledge to teach lessons involving science from industry (Figure 3.10, Appendix B: Table B.8).

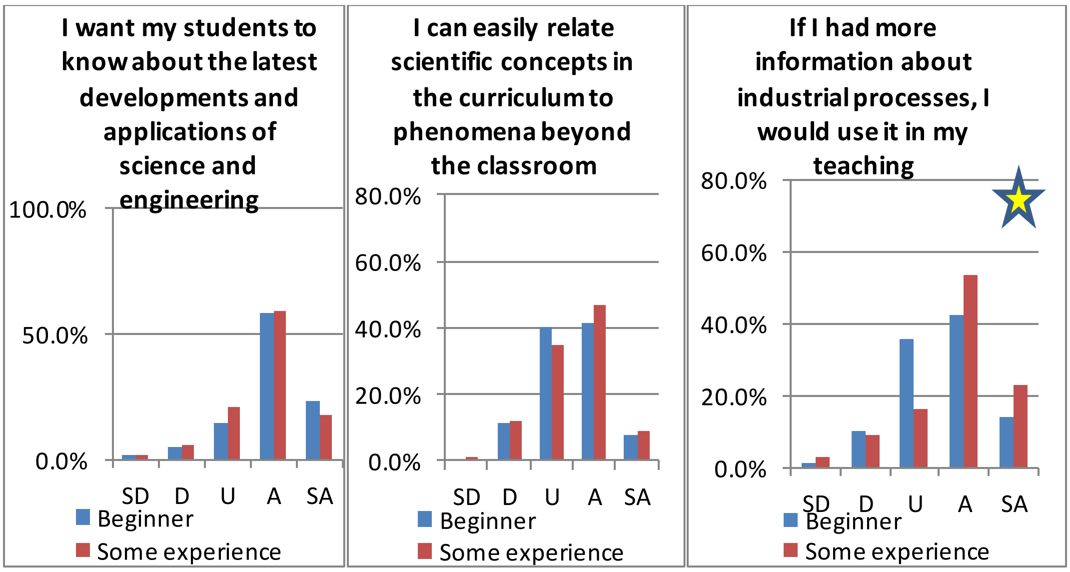


Figure 3.10: PST Initial views of science outside the classroom, based on experience level (*SD, D, U, A, SA = strongly disagree, disagree, uncertain, agree and strongly agree; Balance to 100% relates to percentage of non-respondents)

Examining their views of science shows that the Irish pre-service group are more likely to disagree that scientific knowledge is primarily focussed on knowing facts.

This implies they consider other aspects of science beyond facts such as the processes involved in carrying out scientific research (Appendix B: Table B.13). This is reflected in the items relating to ICK where the Irish PSTs are significantly more positive about their students knowing about the latest developments and applications in science and engineering, using industrial processes in their teaching, and they find it easier to relate scientific concepts in the curriculum to phenomena beyond the classroom (Appendix B: Table B:14).

After the programme, the PSTs now find it easier to relate scientific concepts in the curriculum to phenomena beyond the classroom, but are more uncertain about whether they want their students to know about the latest developments and applications of science and engineering.

3.3.6 Challenges faced by pre-service teachers

Numerous different challenges have been identified which teachers identify when considering or implementing inquiry in the classroom. Teachers have concerns about management issues such as safety, materials and facilities required, unequal distribution of work during group work and getting students' attention (Jackson & Boboc, 2008). Many also believe that it takes up too much time to implement (Anderson, 2007; Lehman, et al., 2006).

To determine what European PSTs consider as challenges to implementing inquiry, they were provided with a list of choices, including an "other" option, and they indicated what they believed to be their top three challenges. PSTs responded to this on both the initial and final questionnaire.

Prior to the TEP, the lack of time to implement inquiry and absence of assistance in school laboratories were the primary challenges identified by the PSTs when trying to implement inquiry lessons for both the BE and SE groups.

Looking at the types of challenges faced by the two groups, the BE group considered intrinsic issues to be more of a challenge overall, such as their limited knowledge of teaching by inquiry and classroom management issues. The SE group considered extrinsic challenges i.e. a lack of a supportive school management and curriculum constraints. After the TEP, the BE groups' challenges were more in-line with those who have some experience with inquiry where they consider extrinsic challenges more of a barrier than the intrinsic challenges that they previously listed (Figure 3.11).

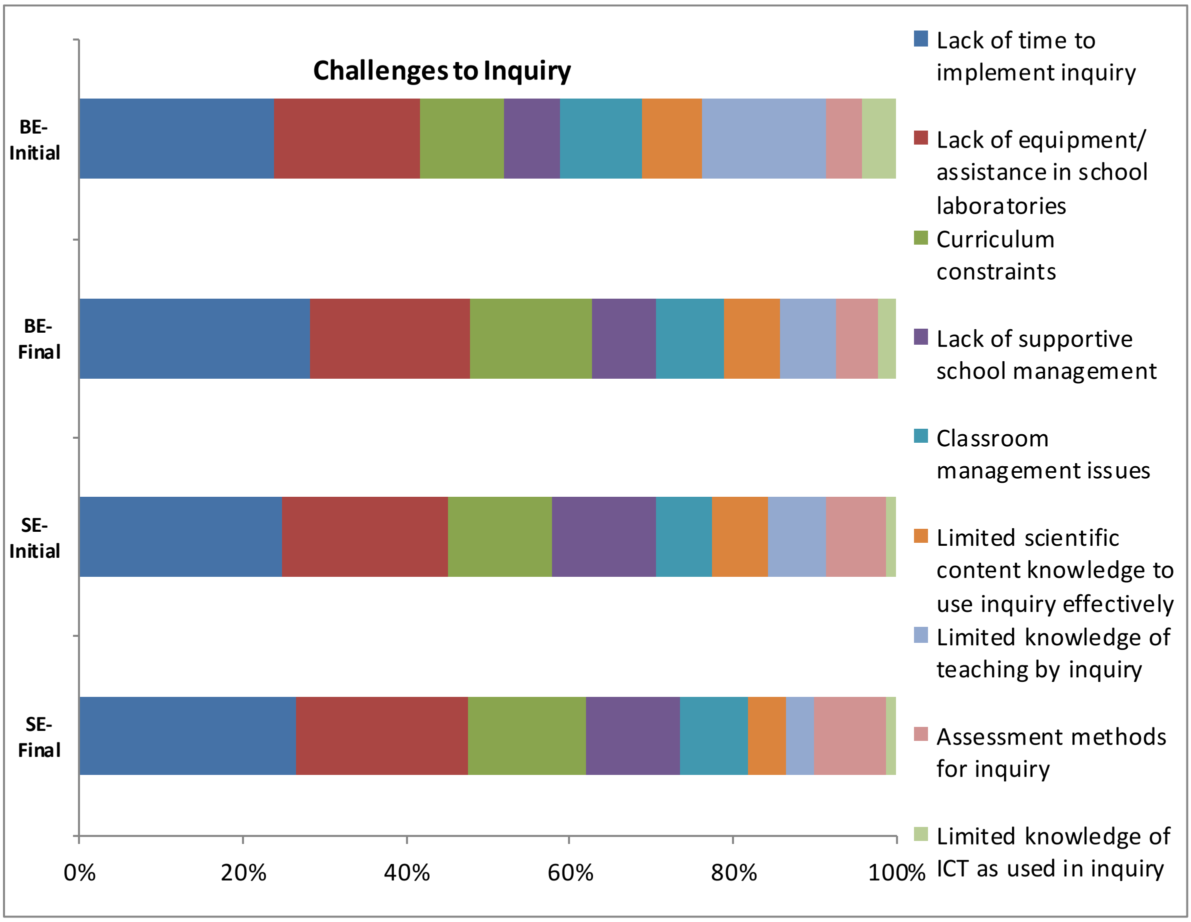


Figure 3.11: PST Initial / Final Challenges to Inquiry

*BE relates to beginners and *SE relates to some experience participants

3.4 Overall conclusions

This study has examined PST's understanding of inquiry and the nature of inquiry across Europe, both prior to and after participating in an inquiry TEP. The findings provide a snapshot of PST's self-reported beliefs and views to inquiry and the role of inquiry in science education. There were several conclusions to be drawn and implications for further inquiry TEPs as a result of the research in this chapter. Overall conclusions can be drawn in relation to PSTs across Europe, specific conclusions regarding Irish PSTs, the result of the Irish pre-service TEP, and implications for further inquiry TEPs for pre-service science teachers.

3.4.1 Understanding and Views towards Inquiry

The European PSTs' understanding of inquiry significantly improved following the inquiry TEP. Developing PSTs' understanding of inquiry and the role of the students and teacher is quite achievable in a TEP such as this where they have the opportunity to experience inquiry. This approach was outlined in Element 1 of the core elements of the ESTABLISH TEPs. Participants with more experience with inquiry reported understanding inquiry more than those with less experience. The greater the PSTs' understanding of inquiry, the more they would consider inquiry as their main teaching method in future. This suggests that increasing PSTs' understanding of inquiry, such as has been achieved here, may increase the likeliness of PSTs using inquiry as their main teaching method in future. Approximately half of the overall group agree that inquiry is suitable for achieving the aims of the curriculum even though they are uncertain about whether it will be easy to teach the curriculum. The majority of the overall cohort also believes that inquiry is suitable for students of varying capabilities, and that students do not need to know a lot of facts before they can participate in inquiry activities.

3.4.2 Self-efficacy, Views of Good Teaching, and Views of Science

Prior to the inquiry TEPs, the overall cohort of PSTs expressed a lack of confidence, skills and knowledge in teaching with inquiry. Those with less experience with inquiry were more uncomfortable with teaching areas of science that they had a limited knowledge of when compared with those who had more experience with inquiry.

Importantly for future TEPs, the PSTs are open to trying new methodologies and are not apprehensive about a change, even when happy with their own teaching. PSTs should be exposed to different pedagogies as a PST, when they are open to trying various methodologies as this indicates that given the right opportunities or support, PSTs would be willing to trial inquiry, or other approaches, in their classrooms.

PSTs agree that developing content knowledge is not more important than developing the thinking and reasoning processes of their students, despite many considering that their goal was to transfer factual knowledge to their students. Worryingly, an understanding that good teachers ask higher order questions is not universal among PSTs. There is a dichotomy between their views on thinking and reasoning processes and factual knowledge in the classroom. Further focus needs to be placed in future TEPs on the use of higher order questioning and reasoning processes.

PSTs don't feel that they have sufficient knowledge of science to implement an inquiry lesson effectively. Those that feel they have insufficient knowledge are unlikely to know how to ask students higher order questions or be comfortable asking questions where they are unsure of the answer themselves.

Prior to the TEP, the beginners with inquiry considered intrinsic issues to be more of a challenge, i.e. their limited knowledge of teaching by inquiry and classroom management issues. Following the TEP, these beginners considered the extrinsic challenges of a lack of a supportive school management and curriculum constraints to be challenges when implementing inquiry.

3.4.3 Irish Sample

The results of the Irish Sample are of particular relevance as the teacher education programme to be discussed in Chapters 5 and 6 involves Irish PSTs of a very similar background.

The Irish sample in this study started with and developed a similar understanding of inquiry to their European counterparts, so the overall approach used is suitable for developing understanding of inquiry in future inquiry teacher education programmes. However, the Irish PSTs were more likely to believe that inquiry only suits very capable students.

In terms of the self-efficacy of the Irish PSTs, they struggle with classrooms where students are carrying out different activities more than their European peers, and they are also more apprehensive about changing their current teaching methods. This indicates that the Irish PSTs need encouragement to change to an alternative instructional method and support during the development of their skills.

Irish PSTs feel more strongly that good teachers focus on curriculum content only and that they should present facts and then explain them. Due to the more broad scope of many inquiry lessons, it would be useful if the PSTs were more open to moving beyond curriculum specific content and teaching in a way that isn't just only about presenting facts and explaining them.

Following the programme, the Irish PSTs agreed significantly more that inquiry will never be their main teaching method which suggests that despite the successes of this programme, changes do need to be made to ensure that the PSTs are comfortable carrying out inquiry in the classroom.

3.4.4 Implications

The approach of immersing PSTs in inquiry in the role of the student is successful at developing PSTs' understanding of inquiry and this approach should be used in further inquiry TEPs.

As PSTs don't feel that they have sufficient knowledge of science to implement an inquiry lesson effectively, a focus on developing PSTs' content knowledge should be considered for future TEPs to address these issues. Additionally, their discomfort with asking higher order questions and questions where they do not know they answer suggests that they need to develop their own skills of encouraging thinking and reasoning strategies in the classroom as part of a TEP.

Future TEPs need to highlight the suitability of inquiry as an approach for all students, as the Irish PSTs were more likely to believe that inquiry only suits very capable students.

Irish PSTs appear to be uncomfortable with teaching in classrooms where their students are carrying out different activities. Future TEPs need to immerse PST in an inquiry environment where various tasks are being carried out by students at the same time, or where students are using different procedures to carry out investigations.

This study has shown that the Irish PSTs are apprehensive about changing their current teaching methods The PSTs need encouragement and support during the development of their skills, so that they may be more comfortable using different teaching methods.

Chapter 5 details how these results and others have been used to develop a further inquiry teacher education programme aimed at pre-service science teachers.

Chapter 4 now presents results on inquiry teacher education programmes focussed on assessment of inquiry.

Chapter 4 – Pre-Service Teachers' Understanding, Views and Practices of Assessment in Inquiry

As discussed in Section 1.2, effective methods for assessing the skills used and developed during inquiry in large scale or high stakes settings remain elusive. Even when teachers are informed about new or alternative assessment strategies, they do not necessarily alter their practices. Numerous different challenges have been highlighted throughout the literature that hinders teachers from assessing in particular ways, or changing assessment practices. Teachers' attachment to traditional grading methods is a major issue, such as marking to a bell-curve or believing poor grades spur students on to improve (Guskey, 2011). Teachers have also highlighted time for new assessments as a barrier to changing their assessment practices. Assessments take time to plan, construct and implement, and this can turn a teacher off changing their current practices (Wolfe & Miller, 1997).

In light of issues such as these, the SAILS project (SAILS, 2014) was developed where the key objectives were to engage teachers in teaching and assessing through inquiry practices, allowing teachers to become more confident and competent to teach science through inquiry and assess skills developed though inquiry in their classrooms. To this end, a series of TEPs have been developed and implemented within the SAILS project.

This study has been carried out within the context of the SAILS project to address the second phase of this research which is:

- Determination of PSTs' understanding and views of assessment in inquiry practices, and how this changes following incorporation of assessment within an inquiry TEP.

4.1 SAILS Teacher Education Programmes

The SAILS project and its aims were discussed in detail in Section 2.3. The SAILS TEPs were developed for in-service teachers to include a set of core elements in all of the TEPs on IBSE and Assessment. The three core elements of the SAILS TEPs are shown in

Figure 4.1. Individual TEPs were adapted to suit the needs of particular cohorts, but the core elements were maintained in each programme.

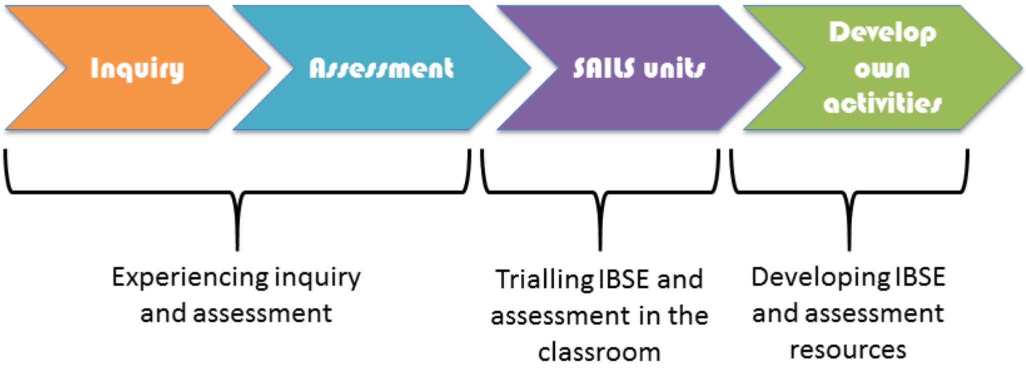


Figure 4.1: The Core Elements of SAILS TEPs

During the TEPs, participants were introduced to inquiry and inquiry assessment by experiencing it, often in the role of the student. The next aspect of the TEP would be to trial SAILS IBSE units in their classrooms. These units have been developed and trialled by teachers from different countries and culturally adapted to suit different situations. The final aspect of the TEPs involved the participants progressing from the role of implementer to that of developer as they designed their own IBSE and assessment units suited to their own needs. The amount of time dedicated to each of these different aspects varied from programme to programme based on what was required by the participants.

For the pre-service programmes, these elements were often incorporated into pre-existing modules as pre-service timetables may not allow for additional programmes. In several of the pre-service programmes, due to the nature of their courses, the PSTs did not have the opportunity to trial units within their classrooms so the focus was on the first element of the PSTs experiencing inquiry and assessment first hand. Therefore, the aim of this chapter was to determine PSTs' understanding of assessment in inquiry and the effect of the TEP on the participants.

4.1.1 Irish Pre-Service Programme

The Irish PST cohort was primarily 2nd year students who would go on to be teachers of either (a) physics and/or chemistry or (b) physical education and biology. These participants had completed the same educational theory and science teaching methodology modules, but their science content backgrounds are different. All of these PSTs had completed three weeks of teaching practice out in schools. The remainder of the Irish cohort were postgraduate students studying for a Professional Masters in Education. These students already possessed a relevant degree in science and were completing a Professional Masters to become teachers of science. Therefore, the content and focus of the TEP for each student cohort varied in order to meet the needs of the cohort.

The pre-service programme did not come in the form of specific workshops. The approach taken was to incorporate the SAILS approach and elements of IBSE into normal modules where the students learn science by inquiry.

The PSTs completing the Professional Masters in Education took part in a series of lectures and workshops which took place in 2 and 3 hour timeslots over a 10 week period. There were several key aspects that formed this programme. The PSTs in this group experienced inquiry activities and were tasked with identifying the specific skills which were focussed on in these tasks. They reviewed video of inquiry classes and formative assessment, and they critiqued various instructional approaches. Assessment was a further focus for this group when they discussed modelling and student representations, and its usefulness as an assessment tool. Samples of classroom dialogue were reviewed and discussion took place on how more scientific discourse could be encouraged in the classroom. Finally, in the role of the student, this group focussed on scientific literacy by using video and newspaper articles relating to science to enhance their own literacy skills. Importantly, this group reflected on the instructional approaches used and presented each week.

Those going on to be physical education and biology teachers carried out inquiry activities within a chemistry laboratory context that can be used at lower second level. The inquiry skills focussed on during these 4 x 3 hour workshops were developing hypothesis, planning and conducting investigations and working collaboratively. Students had to develop criteria for assessing these skills. All of the experiments carried out were chemistry based which was a subject the majority of the group had little background in, so they were learning chemistry as students through inquiry.

The PSTs going on to be physics and/or chemistry teachers carried out and critiqued IBSE activities within a physics laboratory context that can be used at lower second level. The aspects of inquiry and formative on-the-fly assessment focussed on during these 4 x 3 hour workshops were contrasting open and guided inquiry, reducing scaffolding, developing diagrammatic representations, and turning a cookbook experiment into an inquiry activity. The participants watched videos of inquiry classrooms, critiqued the approach, and discussed assessment opportunities within these classes.

Overall, assessment was introduced into pre-service workshops through discussions focussing on determining the criteria for assessment for particular inquiry activities. “Assessment for Learning” strategies were also introduced and students discussed these approaches in terms of what can be assessed and how it can be assessed. Throughout, the PSTs experienced inquiry first-hand in the role of the student. Further details regarding the programmes can be found in the SAILS document “D4.2” (Jonsson, et al., 2014).

4.2 Data, Sample and Analysis

Using questionnaires (see: Section 2.5 and Appendix A.3 – A.5) data was collected from PSTs taking part in SAILS programmes in each country at the beginning of their respective programme. The data from each country was coded and compiled. Following the SAILS TEP, the participants completed a second questionnaire which was again coded and compiled, and the researcher then matched each coded participant to their initial questionnaire. MDS is analysed as described in Section 2.7.4.5. In the section below, the initial profile of PSTs will be presented, with distinctions drawn between those with and without teaching experience (PSTW and PSTWO, respectively). The data will be discussed under the following headings:

- Understanding of inquiry and of assessment in inquiry;
- Inquiry practices and practices assessed;
- Confidence assessing;
- Feedback.

It was important to determine the PSTs' understanding of assessment in inquiry, and that requires the PSTs to have an understanding of inquiry. Determining the PSTs' inquiry assessment practices requires knowledge of what practices they are engaged in in their classrooms. A link between confidence assessing inquiry practices and whether these practices are carried out or assessed is important to determine so that PSTs can be helped to develop their assessment practices. PSTs' understanding and views on feedback reveals information about formative assessment and its place in their classrooms.

In Section 4.4, the changes that occurred following the SAILS TEP will be discussed.

Exploratory factor analysis and Cronbach's Alpha were carried out on the initial sample to determine underlying factors within the questionnaire. The resulting groups that were determined via this method were compiled and analysed using Multi-Dimensional Scaling and cluster analysis. As in Chapter 3, descriptive statistics were conducted on each dataset obtained from each partner. Further details on the quantitative analysis used are discussed in Section 2.7.

In this questionnaire, the participants' were asked to self-rate their experience with inquiry, under four categories shown in Table 4.1, denoted NE, BE, SE and VE.

In total, 269 PSTs completed the initial questionnaire prior to their participation in a SAILS TEP; 30.1% of these participants were male and 69.9% female. 152 of the PSTs had prior experience with teaching, of which 50% had 5 weeks or less in schools and 25% had ≥20 weeks teaching. 117 had no teaching experience. Table 4.2 summarises the whole group showing differences between country groups. It is clear that all country cohorts had PSTs with a variety of experience with inquiry.

The Irish cohort is identified within Table 4.2 as they shall be discussed specifically within this chapter. They are identifiable in any table or graph by the letter "B".

Table 4.1: PST Initial Experience with inquiry

Experience with inquiry	PSTW*	PSTWO**
No / hardly any knowledge about IBSE (NE)	23.7%	57.3%
Some knowledge about IBSE but no practical experience with IBSE in class (BE)	41.4%	38.5%
Some/limited experience with IBSE in class (SE)	32.9%	4.3%
Good knowledge of and regularly use IBSE in class (VE)	1.3%	0.0%

*PSTW – pre-service teachers with teaching experience
**PSTWO – pre-service teachers without teaching experience

Table 4.2: Overview of teacher cohorts that have completed SAILS questionnaires

Country cohort	Number of teachers	Weeks teaching % *			Gender % *		Inquiry experience *			
		≤5 weeks	6-19 weeks	≥20 weeks	M	F	NE	BE	SE	VE
B - Ireland	36	66.7	30.6	2.8	33.3	66.6	19.4	11.1	66.7	2.8
C	1	100	0	0	0	100	0	0	100	0
	34	0			0	100	79.4	20.6	0	0
D	6	0	0	66.7	16.7	83.3	16.67	50	16.67	16.67
E	12	91.6	8.3	0	8.3	91.6	33.3	16.7	41.66	0
	50	0			20	80	50	46	4	0
G	18	0	27.8	72.2	61.1	38.9	27.8	38.9	27.8	0
J	31	100	0	0	22.6	77.4	0	80.6	19.4	0
L	7	100	0	0	57.1	42.9	14.3	85.7	0	0
	10	0			50	50	20	80	0	0
M	41	14.6	24.4	53.7	53.7	46.3	43.9	36.6	19.5	0
	23	0			34.8	65.2	56.5	34.8	8.7	0
Total PSTW	152	50	20.4	26.3	38.2	61.8	23.7	41.4	32.9	1.3
Total PSTWO	117	0			19.7	80.3	57.3	38.5	4.3	0

*Balance relates to percentage of non-respondents

Within the questionnaires completed by the PSTs, specific questions were targeted to those with and without teaching experience. This is due to the fact that PST without teaching experience cannot respond to questions about their current inquiry or assessment practices and therefore responses would not be comparable to those who have teaching experience. Throughout the results section, these two groups are identified and compared. These are referred to as PSTs with (PSTW) and PSTs without (PSTWO) teaching experience.

4.3 Results and Discussion – Prior to TEP Workshops

For the initial analysis, all completed initial questionnaires were used. For the analysis the two groups of PST (PSTW and PSTWO) are considered along with their rating of their experience of inquiry (NE, BE, SE, VE). Due to the small numbers of VE PSTs within the PSTW group, they are not discussed or analysed separately. Equally, the number of SE PSTs in the PSTWO group is too small for separate analysis. Therefore they have been included in the SE and BE groups respectively for analysis. For ease of reading, some statistical values are included in the Appendices, and these will be referred to in the text.

4.3.1 Understanding of Inquiry

The PSTs' understanding of inquiry was determined from their responses to three items (PSTW α=0.878, PSTWO α=0.760). Responses to questions relating to understanding of inquiry for PSTW and PSTWO are shown in Figures 4.2 and 4.3, respectively. The level of a PST's understanding seems related to their prior experience with inquiry, rather than their teaching experience (Figures 4.2 and 4.3). The BE group had significantly greater understanding of inquiry than the NE group in both PSTW and PSTWO, with the SE group also having a significantly greater understanding than the NE group in PSTW. Statistical details can be found in Appendix C (Tables C.1, C.5 – C.7 for PSTW and C.3 & C.8 for PSTWO).

The Irish sample did not differ significantly from the European sample in their understanding of inquiry.

These results agree with those in Chapter 3, showing that PSTs have not developed a deep understanding of inquiry, both the Irish cohort and also international cohort.

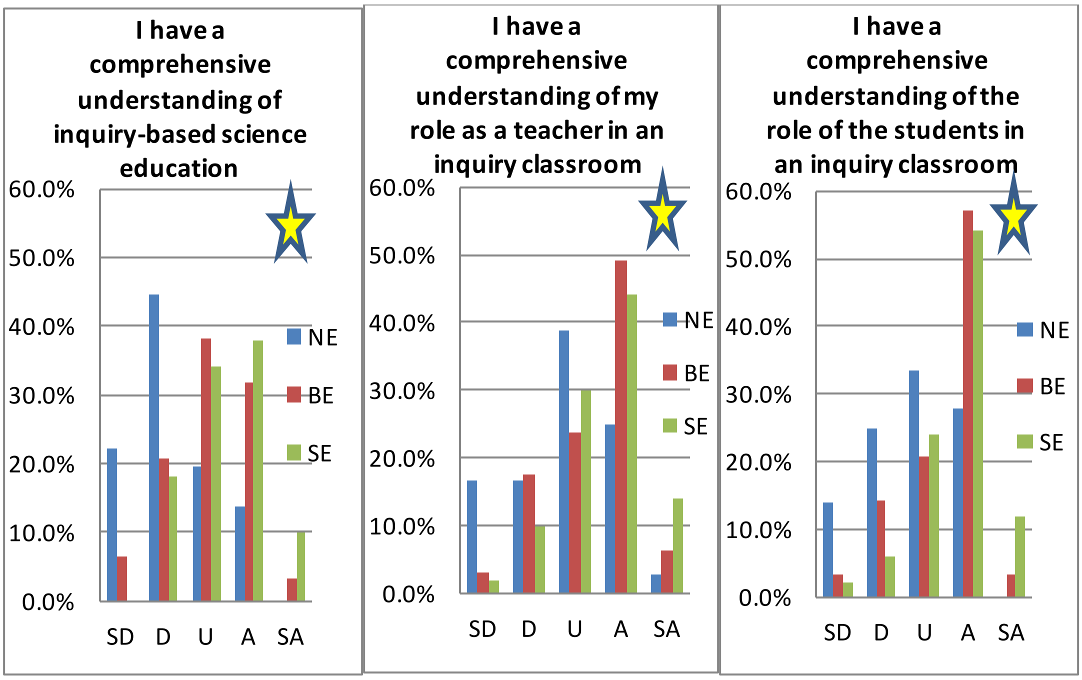


Figure 4.2: PSTW Initial Understanding of Inquiry, based on experience level
(SD , D, U, A, SA = strongly disagree, disagree, uncertain, agree and strongly agree; Star indicates significant differences between the cohorts on the question)

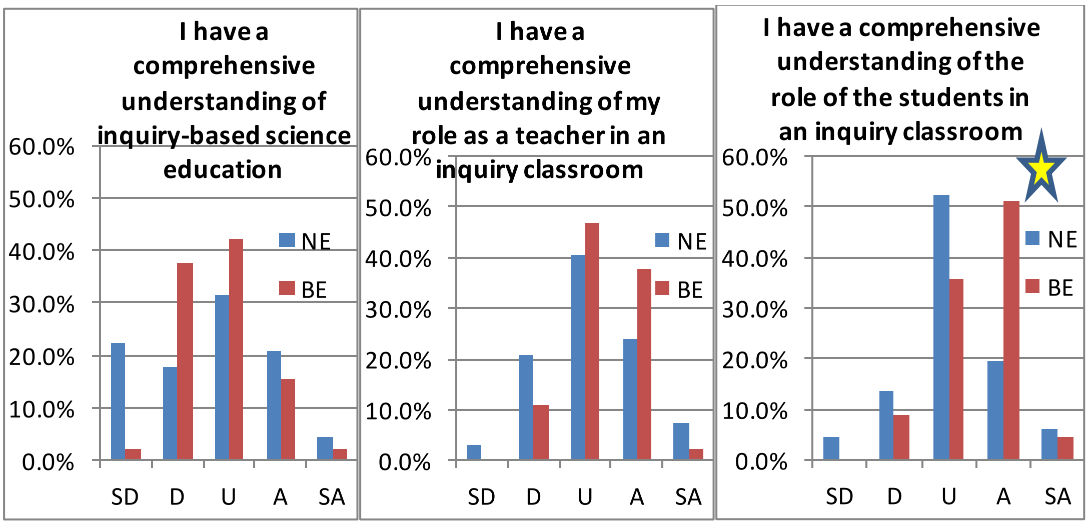


Figure 4.3: PSTWO Initial Understanding of Inquiry, based on experience level
(SD ,D, U, A, SA = strongly disagree, disagree, uncertain, agree and strongly agree; Star indicates significant differences between the cohorts on the question)

Many of the cohort groups had a mixture of PSTW and PSTWO. The PSTW had a significantly greater understanding of inquiry than the PSTWO. The classroom experience may have allowed them to develop a greater understanding of what the methodology may look like (Appendix C: Table C.9). This can be seen in Figure 4.4, where PSTs from different cohorts without prior experience are generally located farther from the ideal response than those with experience. From Figure 4.4 it is clear that PSTWO are farther from the ideal response than PSTW from within the same country cohort.

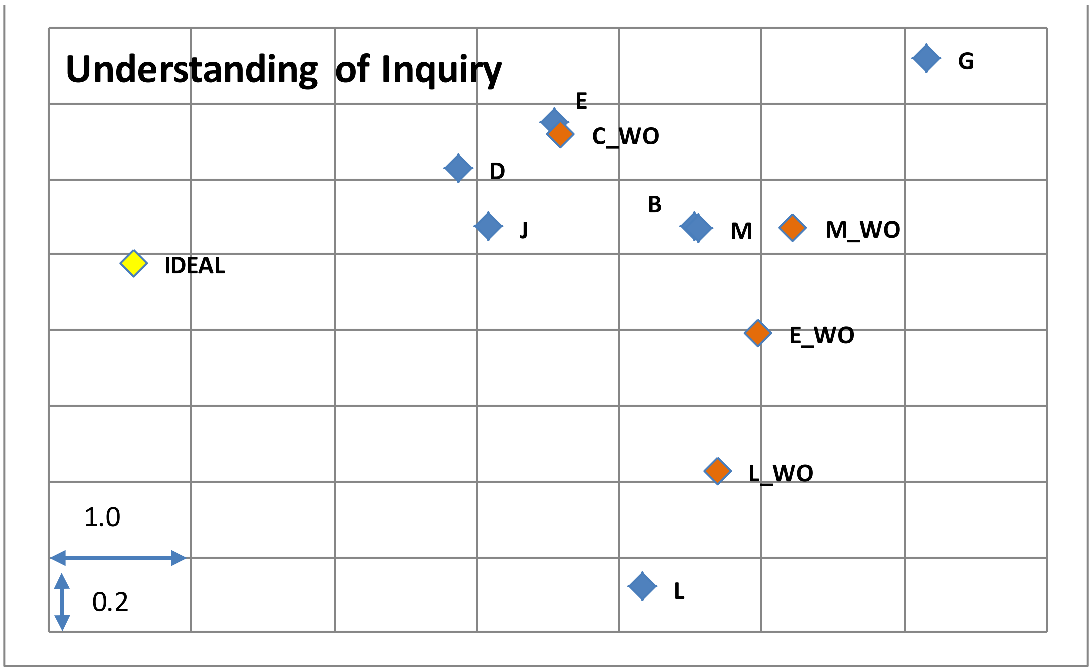


Figure 4.4: PSTW and PSTWO Changes in Understanding of inquiry – MDS Analysis
where _WO indicates a PSTWO cohort, letter only implies PSTW

4.3.2 Understanding of Assessment in Inquiry

The understanding of assessment in inquiry is determined from PSTs responses to questions asking them to rate their understanding of the nature of IBSE assessment, their confidence with using multiple assessment methods, and their ability to highlight strengths and weaknesses of a particular students' work. The overall cohort shows a range of understanding.

When comparing the participants who have teaching experience to those who do not have teaching experience, there are no significant differences between their responses. This indicates that the participants' responses in terms of inquiry assessment are the same irrespective of their classroom teaching. In the PST group overall, there are differences between the BE and SE groups within the PSTW grouping, and NE and BE groups within the PSTWO grouping in their understanding of the nature of assessment in the inquiry classroom, as shown in Figures 4.5 and 4.6 (Appendix C: Table C.3 for PSTW and C.4 for PSTWO). The Irish sample did not differ significantly from the European sample in their understanding of assessment in inquiry.

These results are consistent with understanding of inquiry, indicating there are deficiencies in PSTs' understanding of assessment in inquiry, in addition to inquiry itself, particularly in using different assessment methods, and nature of assessments that are possible in an inquiry classroom. The groups were relatively more able to highlight the strengths and weaknesses of a students' work, however, this may be based on limited types of assessments. The following section addresses this.

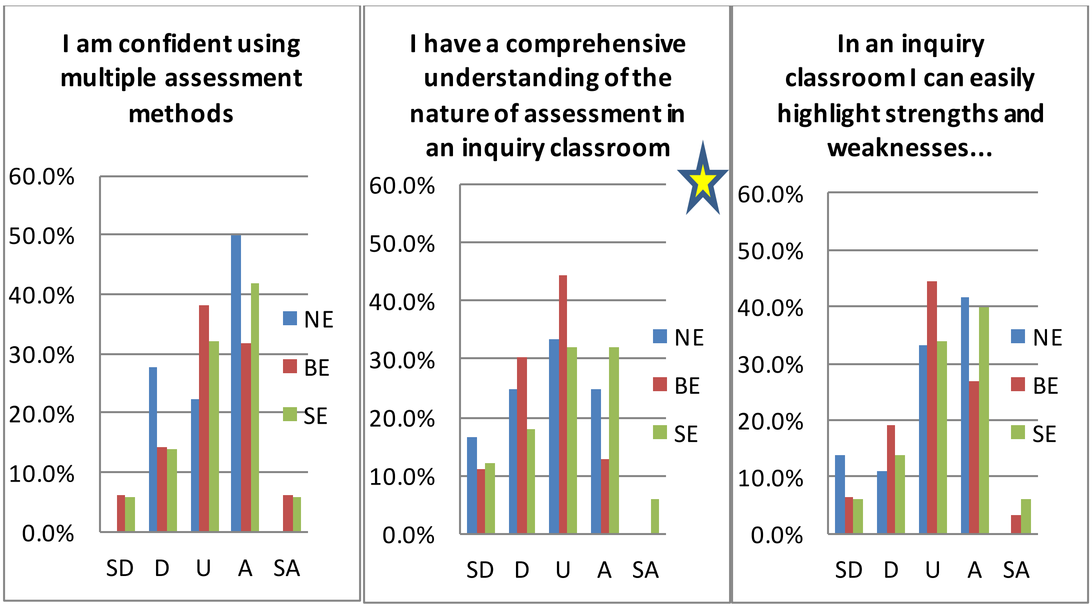


Figure 4.5: PSTW Initial Understanding of Inquiry Assessment, based on experience level (SD , D, U, A, SA = strongly disagree, disagree, uncertain, agree and strongly agree; Star indicates significant differences between the cohorts on the question)

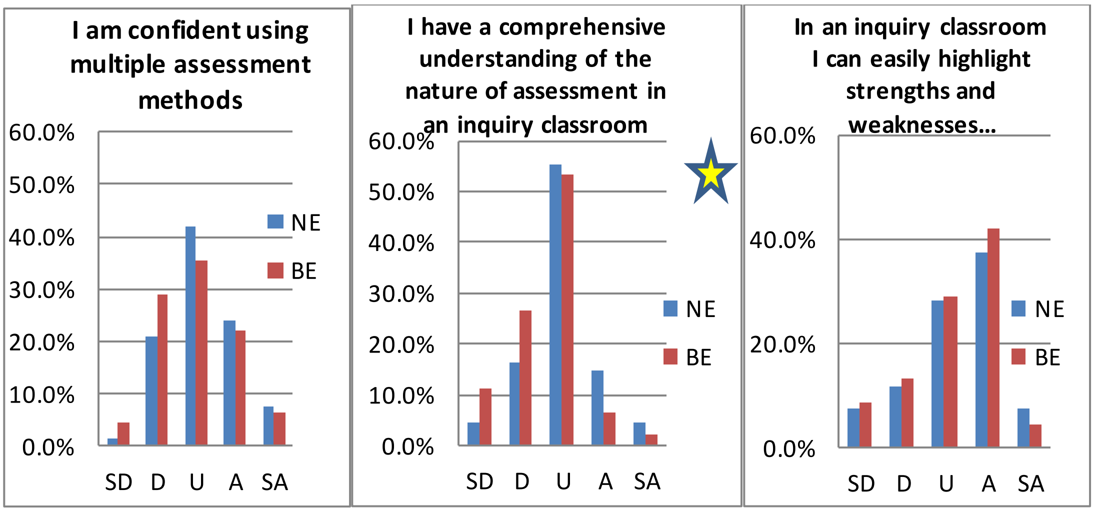


Figure 4.6: PSTWO Initial Understanding of Inquiry Assessment, based on experience level
(SD , D, U, A, SA = strongly disagree, disagree, uncertain, agree and strongly agree; Star indicates significant differences between the cohorts on the question)

4.3.3 Practices, assessment and confidence

Within this section, the PSTW and PSTWO groups are considered separately as the PSTWO group cannot answer questions about practices that have occurred in the classroom, only practices that they think are important and would like to assess in future.

4.3.3.1 PSTW Practices, assessment and confidence

The PSTW indicated their agreement to the statement "In my classroom, this practice almost always occurs" based on a list of inquiry practices. Table 4.3 shows the responses of the Irish participants to these items, and Table 4.7 shows the whole of the PSTWs responses to these items (more detailed table of responses can be found in Appendix C: Table C.2).

4.3.3.1.1 Irish PSTW Practices, Assessment and Confidence

Overall, many of the Irish PSTs indicated that they carry out many of these inquiry practices within their classrooms. The practices that the Irish PSTs stated they carried out the most were that each student has a role as investigations are conducted (Q21), students develop their own conclusions (Q25), they understand why the data they collect is important (Q23), they analyse their own data (Q24), and they justify their conclusions (Q27). The practices their students carry out the least are critiquing information from other sources, e.g. newspapers, web links, magazines (Q29), designing (Q18) and conducting (Q20) their own procedures of an investigation. This indicates that Irish PSTs are carrying out some inquiry practices within their classrooms, however their students are not typically involved in the designing of questions and procedures for investigations.

The most assessed practices by the Irish PSTs were that each student has a role as investigations are conducted (Q21), students develop their own conclusions (Q25), they understand why the data they collect is important (Q23). In terms of the confidence of Irish PSTs, they are most confident assessing inquiry practices. There is a clear link between what is practiced, where they are confident assessing, and what is assessed by the Irish PSTs.

There are significant differences between the responses of the Irish PSTs and the whole group of PSTW based on their inquiry practices, what they assess, and their confidence in assessing these practices, often based on the same inquiry practices. The greatest number of differences was on the practices they say that they assess in their classrooms. In the majority of cases, the Irish PSTs carry out the inquiry practices more, assess more, and are more confident in their assessment practices than their European counterparts. The only aspect where the Irish participants conduct less, assess less, and are less confident is related to students critiquing information from other sources in their classrooms. These are shown in Tables 4.4, 4.5 and 4.6.

4.3.3.1.2 Whole Group PSTW Practices, Assessment, and Confidence

The most carried out practices by the whole group (see Table 4.7) were that students understand why the data they are collecting is important (Q23), they develop their own conclusions for investigations (Q25), they present their results and conclusions (Q28), and they have opportunities to talk and listen to each other (Q30). However, limited opportunities are provided for students to conduct their own procedures of an investigation (Q20) and to determine which data to collect (Q22).

There were significant differences between the practices of the PSTW who have different levels of experience with inquiry. In each case, the responses indicate that those with greater experience with inquiry carry out these practices more than those with less experience. An overview of these differences can be seen in Table 4.7, and further details can be found in Appendix C: Tables C.5 – C.7.

When asked which of these practices they assess, students developing their own conclusions (Q25), justifying their conclusions (Q27), and analysing their own data (Q24) are assessed by the most PSTW. Despite PSTW's students developing their own conclusions and being assessed on this practice, they are not involved in considering different ways of interpreting evidence and forming conclusions (Q26). The focus may be on stating the conclusion from the specific predefined inquiry. From this data, it is not clear as to the nature of the inquiry.

There are significant differences in the assessment practices of the PSTW of different inquiry experience levels, with the BE group of PSTW assessing numerous practices less than the NE and SE PSTW. Although the differences span across different practices, it is important to note there were no differences on items relating to students developing their own research questions, and designing or critiquing investigations which are significant aspects of the inquiry process. An overview of these differences can be seen in Table 4.7, and statistical details can be found in Appendix C: Tables C.5 – C.7.

The PSTW's are most confident assessing students presenting their results (Q28) and critiquing information from other sources (Q29), despite the latter practice being one of the practices they assess the least. They are least confident assessing students formulating (Q16) and refining questions (Q17) which can be answered by investigations. The responses of the different inquiry experience levels show that those with more experience are significantly more confident assessing many of these practices (Table 4.7, and statistical details can be found in Appendix C: Tables C5 - C7).

Looking closely at these responses, there is a link between what the PSTW practice, what they assess, and what they are confident assessing. There are moderate correlations between each of these (with the exception of Q23), indicating that if PSTs are carrying out these practices, they are more likely to be assessing them, and they are more likely to be confident assessing them (Appendix C: Table C.13).

These results support ideas which have been previously discussed. Teachers teach as they were taught themselves and the PSTW were unlikely to have been exposed to inquiry teaching. PSTW carried out less student-controlled inquiry practices such as students developing their own procedures and determining which data to collect which they may not have had experience with. As was previously noted by Feiman-Nemser & Buchmann, "*future teachers cannot be expected to recognize that what they know about classroom life is only part of a universe of possibilities. They need help*" (Feiman-Nemser & Buchmann, 1983).

In Section 3.3.3, it was shown that PSTs like knowing the answer to what they are asking, and what is expected from investigations and they assess according to that. Similarly here, the PSTs are confident assessing what they know, evidenced by the relationship between their confidence assessing and the practices they carry out and assess.

As in Section 3.3.4, the PSTs don't recognise assessment opportunities in terms of the thinking processes in inquiry, or the social aspects of constructivism theories of learning. The PSTs assess outcomes of learning rather than processes.

Table 4.3: Irish Group - PSTW responses to Practices, assessment and confidence,

PSTW	In my classroom, this practice almost always occurs (A)			Do you currently assess this? (B)	I am confident in assessing this practice (C)		
	SD/D	U	A/SA	Yes	SD/D	U	A/SA
16. Students formulate questions which can be answered by Investigation	27.8%	36.1%	36.1%	47.2%	38.9%	36.1%	22.2%
17. Time is devoted to refining student questions so that they can be answered by investigations.	19.4%	38.9%	41.7%	44.4%	36.1%	30.6%	30.6%
18. Students design their own procedures for investigations.	50.0%	30.6%	19.4%	41.7%	50.0%	27.8%	22.2%
19. Students engage in critiquing the procedures that are used when they conduct investigations.	33.3%	25.0%	38.9%	61.1%	33.3%	27.8%	33.3%
20. Students conduct their own procedures of an investigation.	47.2%	36.1%	16.7%	47.2%	44.4%	33.3%	22.2%
21. Each student has a role as investigations are conducted	5.6%	8.3%	86.1%	91.7%	11.1%	11.1%	75.0%
22. When conducting an investigation, students determine which data to collect.	44.4%	27.8%	22.2%	44.4%	41.7%	22.2%	30.6%
23. When conducting an investigation, students understand why the data they are collecting is important.	5.6%	19.4%	75.0%	94.4%	11.1%	33.3%	55.6%
24. Students analyse their own data.	5.6%	19.4%	75.0%	88.9%	16.7%	19.4%	63.9%
25. Students develop their own conclusions for investigations.	8.3%	13.9%	77.8%	91.7%	2.8%	33.3%	63.9%
26. Students consider a variety of ways of interpreting evidence when making conclusions.	22.2%	41.7%	36.1%	52.8%	36.1%	33.3%	30.6%
27. Students justify their conclusions.	13.9%	11.1%	75.0%	80.6%	13.9%	25.0%	61.1%
28. Students present their results and conclusions from an investigation.	11.1%	22.2%	66.7%	83.3%	16.7%	30.6%	52.8%
29. Students critique information from other sources, e.g. newspapers, web links, magazines	72.2%	16.7%	11.1%	22.2%	58.3%	25.0%	13.9%
30. Students have opportunities to talk and listen to each other, in the inquiry classroom.	8.3%	19.4%	72.2%	83.3%	11.1%	25.0%	61.1%
31. Students have opportunities to develop empathy with peers, in the inquiry classroom.	16.7%	41.7%	41.7%	41.7%	30.6%	36.1%	30.6%
32. Students have the opportunity to respect and understand each other in the inquiry classroom	2.8%	30.6%	66.7%	69.4%	22.2%	25.0%	50.0%

SD/D=strongly disagree/disagree; U=uncertain, A/SA=agree/strongly agree

Table 4.4: Differences between Irish and European participants' classroom inquiry practices

Statement – Classroom inquiry practices	$\chi^2(2)$	p	Mean rank - Ireland	Mean rank - Europe
Each student has a role as investigations are conducted	18.098	.000	101.92	67.89
When conducting an investigation, students understand why the data they are collecting is important	6.343	.012	90.57	70.74
Students develop their own conclusions for investigations	4.654	.031	88.92	71.96
Students critique information from other sources, e.g. newspapers, web links, magazines	16.563	.000	50.47	83.40

**See Section 2.7.1 for explanation of Kruskal-Wallis test

Table 4.5: Differences between Irish and European participants' classroom assessment practices

Statement – What they currently assess	$\chi^2(2)$	p	Mean rank – Ireland	Mean rank - Europe
Students engage in critiquing the procedures that are used when they conduct investigations	5.486	.019	61.81	78.90
Each student has a role as investigations are conducted	25.132	.000	48.25	84.11
When conducting an investigation, students understand why the data they are collecting is important	24.8338	.000	48.67	83.97
Students analyse their own data.	10.985	.001	58.33	80.92
Students develop their own conclusions for investigations	11.913	.001	58.29	81.54
Students present their results and conclusions from an investigation	7.633	.006	61.00	80.08
Students critique information from other sources, e.g. newspapers, web links, magazines	4.817	.028	87.72	72.33
Students have opportunities to talk and listen to each other, in the inquiry classroom	14.926	.000	54.50	82.13
Students have the opportunity to respect and understand each other in the inquiry classroom	9.298	.002	58.11	79.77

**See Section 2.7.1 for explanation of Kruskal-Wallis test

Table 4.6: Differences between Irish and European participants' confidence in classroom assessment practices

Statement – Confidence assessing	$\chi^2(2)$	p	Mean rank - Ireland	Mean rank - Europe
Each student has a role as investigations are conducted	19.530	.000	101.59	66.11
When conducting an investigation, students understand why the data they are collecting is important	7.191	.007	90.51	69.35
Students develop their own conclusions for investigations	6.859	.009	90.65	70.11
Students critique information from other sources, e.g. newspapers, web links, magazines	11.374	.001	53.77	80.92
Students have opportunities to talk and listen to each other, in the inquiry classroom	6.753	.009	89.81	69.06

**See Section 2.7.1 for explanation of Kruskal-Wallis test

Table 4.7: PSTW responses to Practices, assessment and confidence

PSTW	In my classroom, this practice almost always occurs (A)				Do you currently assess this? (B)		I am confident in assessing this practice (C)			
	SD/D	U	A/SA	Sig diff	Yes	Sig diff	SD/D	U	A/SA	Sig diff
16. Students formulate questions which can be answered by Investigation	19.1%	39.5%	40.1%	-	46.7%	-	37.5%	30.9%	29.6%	-
17. Time is devoted to refining student questions so that they can be answered by investigations.	26.3%	28.9%	43.4%	-	34.9%	-	40.1%	31.6%	25.7%	BE/ SE
18. Students design their own procedures for investigations.	40.8%	25.7%	32.9%	-	42.1%	-	36.8%	32.2%	28.9%	-
19. Students engage in critiquing the procedures that are used when they conduct investigations.	36.2%	23.7%	38.8%	NE/SE BE/SE	44.7%	BE/SE	40.8%	28.3%	27.6%	NE/SE BE/ SE
20. Students conduct their own procedures of an investigation.	42.1%	28.9%	27.6%	-	44.1%	-	40.1%	31.6%	25.7%	-
21. Each student has a role as investigations are conducted	25.0%	16.4%	57.9%	NE/SE BE/SE	54.6%	NE/BE BE/SE	29.6%	27.6%	40.1%	NE/SE BE/ SE
22. When conducting an investigation, students determine which data to collect.	40.8%	29.6%	27.0%	-	36.2%	-	39.5%	33.6%	23.7%	NE/SE
23. When conducting an investigation, students understand why the data they are collecting is important.	16.4%	30.9%	51.3%	BE/SE	57.9%	NE/BE BE/SE	26.3%	34.9%	36.2%	BE/SE
24. Students analyse their own data.	15.8%	23.7%	59.9%	BE/SE	65.1%	BE/SE	23.0%	27.6%	47.4%	-
25. Students develop their own conclusions for investigations.	13.2%	19.7%	66.4%	BE/SE	67.8%	NE/BE BE/SE	15.8%	35.5%	46.7%	NE/SE BE/ SE
26. Students consider a variety of ways of interpreting evidence when making conclusions.	29.6%	35.5%	33.6%	NE/SE	42.8%	BE/SE	36.2%	34.9%	27.6%	NE/SE BE/ SE
27. Students justify their conclusions.	13.2%	25.0%	60.5%	NE/SE	67.1%	BE/SE	20.4%	28.9%	49.3%	NE/SE
28. Students present their results and conclusions from an investigation.	14.5%	17.8%	66.4%	-	63.2%	NE/BE BE/SE	21.1%	27.0%	49.3%	-
29. Students critique information from other sources, e.g. newspapers, web links, magazines	44.1%	23.0%	31.6%	NE/BE NE/SE	37.5%	-	35.5%	31.6%	30.3%	-
30. Students have opportunities to talk and listen to each other, in the inquiry classroom.	13.2%	20.4%	64.5%	NE/SE	54.6%	NE/BE BE/SE	24.3%	30.9%	41.4%	NE/SE BE/ SE
31. Students have opportunities to develop empathy with peers, in the inquiry classroom.	17.1%	28.9%	52.0%	NE/SE	34.2%	NE/BE BE/SE	34.9%	33.6%	28.9%	BE/SE
32. Students have the opportunity to respect and understand each other in the inquiry classroom	9.2%	21.7%	67.1%	NE/SE	46.1%	NE/BE BE/SE	27.0%	25.0%	44.7%	BE/SE

* significant differences based on experience level – (Underlined group means they practice more/ assess more/ is more confident)

SD/D=strongly disagree/disagree; U=uncertain, A/SA=agree/strongly agree

4.3.3.2 PSTWO Practices, assessment and confidence

The PSTWO could not be asked about their practices in the classroom as they had not yet had the opportunity to go out to schools. Instead, the PSTWO indicated their level of agreement to the statement “I think that this practice is very important in the classroom” about each of the inquiry practices that were also listed for the PSTW. Results are shown in Table 4.8.

Overall, the PSTWO were very positive in what they think is important to practice in the classroom. Students developing conclusions (Q25), presenting results and conclusions (Q28) and having opportunities to talk and listen to each other (Q30) are of most importance to the PSTWO. Of less importance to the PSTWO is students determining which data to collect (Q22), conducting their own procedures (Q20) and critiquing the procedures that are used when conducting investigations (Q19).

When asked which of these practices they want to assess in future, they are positive about the majority of items, particularly those they considered important to practice, such as students developing their own conclusions (Q25). The practices that they want to assess the least are also similar to what they consider as least importance to practice, particularly students determining which data to collect (Q22).

Many of the PSTWO are confident assessing the practices, despite their inexperience. However, they were least confident with assessing students formulating (Q16) and refining (Q17) questions which can be answered by investigations. It is clear that PSTs need support developing their skills at generating and supporting student questions which can be answered by investigations.

There are significant differences between the responses based on the experience levels’ in inquiry. In each instance, the NE group consider the practices more important, want to assess them more in future and are more confident assessing them than the BE group. An overview of the responses and these differences can be seen in Table 4.8, and further details can be found in Appendix C: Table C.8.

When comparing the PSTW to the PSTWO, the PSTWO were significantly more confident with assessing these practices in their future classrooms than the PSTW are currently. From the MDS analysis (Figure 4.7) PSTWO are closer to the ideal response than the PSTW from within the same country cohort, for example there is a large gap in the confidence of the PSTW and PSTWO from country E, shown in Figure 4.7.

This implies that the PSTWO are more open to the possibilities of looking at a range of assessment opportunities. (Appendix C: Table C.9). These differences are clear in Figure 4.7.

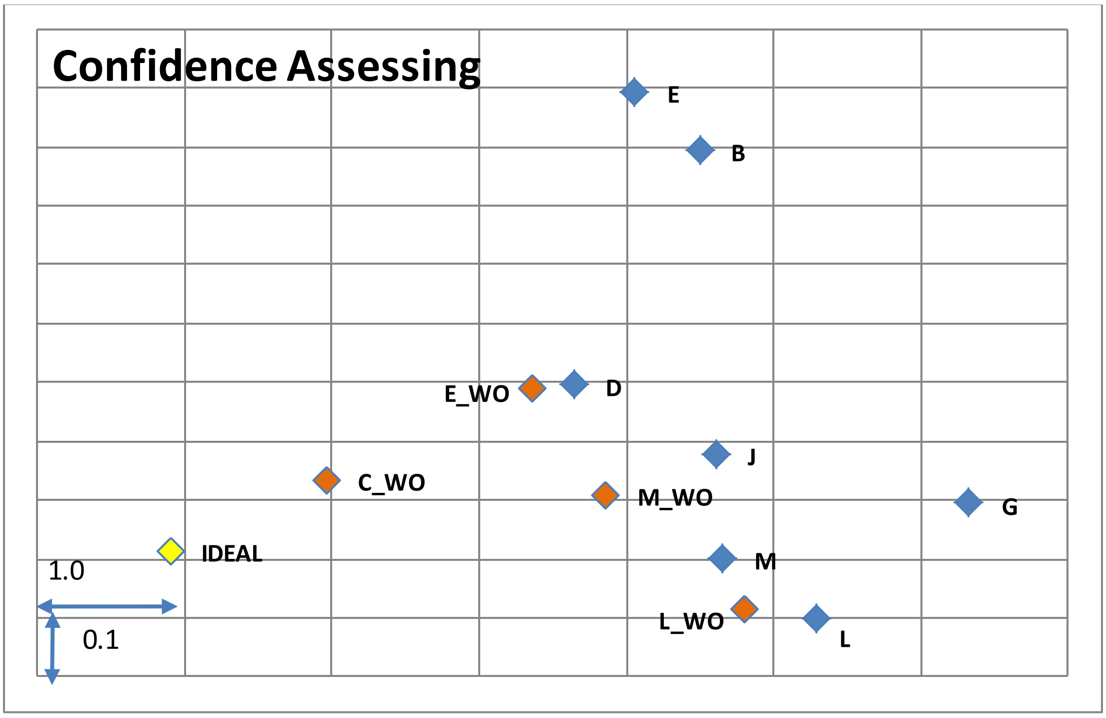


Figure 4.7: PSTW and PSTWO Changes in confidence assessing – MDS Analysis
(PSTW α = 0.943, PSTWO α = 0.864) where _WO indicates a PSTWO cohort – Letter only implies PSTW cohort

Table 4.8: – PSTWO responses to Practices, assessment and confidence

PSTWO	I think that this practice is very important in the classroom (A)				Do you want to assess this practice in future? (B)		I am confident that I can assess this practice (C)			
	SD/D	U	A/SA	Sig diff	Yes	Sig diff	SD/D	U	A/SA	Sig diff
16. Students formulate questions which can be answered by Investigation	1.7%	9.4%	88.9%	-	86.3%	-	11.1%	41.9%	45.3%	-
17. Time is devoted to refining student questions so that they can be answered by investigations.	5.1%	21.4%	73.5%	-	76.1%	NE/BE	13.7%	38.5%	47.0%	NE/BE
18. Students design their own procedures for investigations.	6.0%	12.8%	80.3%	-	89.7%	-	6.8%	32.5%	59.8%	-
19. Students engage in critiquing the procedures that are used when they conduct investigations.	6.0%	22.2%	69.2%	-	82.9%	-	8.5%	32.5%	55.6%	-
20. Students conduct their own procedures of an investigation.	5.1%	25.6%	68.4%	-	84.6%	NE/BE	8.5%	33.3%	55.6%	-
21. Each student has a role as investigations are conducted	6.8%	7.7%	85.5%	-	84.6%	-	12.8%	19.7%	65.8%	-
22. When conducting an investigation, students determine which data to collect.	17.1%	26.5%	55.6%	-	71.8%	-	15.4%	24.8%	58.1%	-
23. When conducting an investigation, students understand why the data they are collecting is important.	3.4%	8.5%	87.2%	-	91.5%	-	7.7%	23.9%	66.7%	-
24. Students analyse their own data.	6.0%	11.1%	82.9%	-	89.7%	-	7.7%	20.5%	70.1%	-
25. Students develop their own conclusions for investigations.	1.7%	6.8%	91.5%	-	94.0%	-	6.0%	17.1%	76.1%	-
26. Students consider a variety of ways of interpreting evidence when making conclusions.	2.6%	16.2%	80.3%	-	85.5%	-	8.5%	28.2%	60.7%	-
27. Students justify their conclusions.	3.4%	9.4%	86.3%	-	90.6%	-	7.7%	17.9%	73.5%	-
28. Students present their results and conclusions from an investigation.	3.4%	3.4%	92.3%	NE/BE	92.3%	NE/BE	5.1%	17.1%	76.9%	-
29. Students critique information from other sources, e.g. newspapers, web links, magazines	4.3%	15.4%	80.3%	-	85.5%	-	8.5%	23.1%	66.7%	-
30. Students have opportunities to talk and listen to each other, in the inquiry classroom.	1.7%	6.8%	91.5%	NE/BE	85.5%	-	4.3%	26.5%	68.4%	NE/BE
31. Students have opportunities to develop empathy with peers, in the inquiry classroom.	7.7%	12.0%	79.5%	NE/BE	76.1%	NE/BE	12.0%	29.1%	57.3%	NE/BE
32. Students have the opportunity to respect and understand each other in the inquiry classroom	4.3%	9.4%	86.3%	NE/BE	81.2%	NE/BE	12.0%	19.7%	67.5%	NE/BE

*significant differences based on experience level – (Underlined group means they practice more/ assess more/ is more confident)

SD/D=strongly disagree/disagree; U=uncertain, A/SA=agree/strongly agree

4.3.4 Views on Student Learning and Feedback

A number of questions elicited general views of the PSTs on the nature of feedback to support learning. Feedback is considered by many experts as an important aspect of assessment for learning (Hattie, 2009; Black, et al., 2003; Clarke, 2003), and has been referred to as being it "*among the most critical influences on student learning*" (Hattie & Timperley, 2007). Feedback has been show to increase learner satisfaction and their persistence (Kluger & Denisi, 1996) and the practice contributes to students embracing more productive learning strategies (Vollmeyer & Rheinberg, 2005). However, what is considered to be "good feedback' is disputed (Shute, 2008).

It has been found that even though students' trust in peer feedback grows after carrying out peer assessment, the major difficulty lies in increasing students' confidence in their own feedback providing skills. As such, a large part of the challenge of carrying out peer feedback and assessment is convincing students that they can assess their own work, and the work of others, effectively (van Gennip, et al., 2010). As such, it was important to determine information regarding PSTs' views of peer feedback.

Typically, feedback given in the form of a reward or grades enhances student ego rather than task involvement. This can be damaging to the self-esteem of low achievers, and can be particularly damaging to students' motivation and learning in high-stakes environments (Black, et al., 2003). As such, feedback should focus on improvement of the material or task itself, rather than on assigning a value which the student may associate with themselves. As such it was considered important to determine what PSTs believe the purpose of feedback is.

4.3.4.1 Irish PSTW Views on Student Learning and Feedback

Overall, the Irish teachers are quite positive about the benefits of feedback on students' learning. There are significant differences between the responses of the Irish PSTs and the whole group PSTW (Table 4.9). The Irish PSTs are more inclined to agree than their European peers that giving feedback to students is important because it helps them to learn. The Irish cohort are less likely to believe that the point of feedback is to make students feel good about themselves than their European counterparts. They were also significantly less likely to believe that quality feedback happens interactively and immediately in the classroom while students are learning.

Table 4.9: Significant differences between Irish PST and whole group PSTW, regarding feedback

Statement	$\chi^2(2)$	p	Mean rank - Ireland	Mean rank - Europe
Giving students feedback is important because it helps them to learn	5.033	.025	88.67	72.72
The point of feedback is to make students feel good about themselves	5.173	.023	61.89	80.26
Quality feedback happens interactively and immediately in the classroom while students are learning	11.619	.001	56.19	82.80

See Section 2.7.1 for explanation of Kruskal-Wallis test

4.3.4.2 Whole group PSTW and PSTWO Views on Student Learning and Feedback

Overall, the whole group PSTW and PSTWO hold similar views on feedback and on the positive impact of feedback. They believe that feedback helps students to learn (Q7) and evaluate their own work (Q13), what to include in their work (Q8), and is a two-way process between teacher and student (Q15) (Appendix C: Tables C.1 & C.3).

The PSTs have various views however on whether quality feedback happens interactively and immediately in the classroom (Q11), if it is useless when it takes more than a week (Q12), and whether peers are the best source of feedback (Q14).

There were also various views on whether the point of feedback is to make students feel good about themselves. The PSTWO group were more likely to believe that feedback should benefit students' ego (Appendix C: Table C.9).

4.4 Results and Discussion - Effect of Workshops on PST

In total, 175 PSTs completed both the initial and final questionnaires to provide a matched sample with which to determine effects of the TEP, 91 PSTW and 84 PSTWO. PSTW and PSTWO remain in the categories already assigned.

As part of the Irish SAILS TEP, the PSTs experienced inquiry and inquiry assessment first hand. They carried out and critiqued IBSE activities, and formative, on-the-fly assessment was built in to these activities. Assessment was introduced through discussions focussing on determining the criteria for assessment for particular inquiry activities. There was a focus on using modelling in inquiry for assessment and developing diagrammatic representations.

All of the Irish PSTs had the opportunity to experience inquiry and inquiry assessment, but due to the nature of their programmes they did not necessarily have the opportunity to trial IBSE and assessment activities in a classroom, or develop their own resources. Changes in the PSTs' responses following the SAILS workshops will be discussed under the headings as indicated in Section 4.3.

4.4.1 Understanding of Inquiry

The Irish PSTs changed significantly on all three items for understanding of inquiry following the SAILS TEPs. These changes can be seen in Table 4.10 and Figure 4.8. This greater understanding means that the Irish TEP is suitable for developing PSTs' understanding of inquiry.

Table 4.10: Significant Changes in Irish PSTs' Understanding of Inquiry

Statement	Z	P
1. I have a comprehensive understanding of inquiry-based science education	-3.218	.001
2. I have a comprehensive understanding of my role as a teacher in an inquiry classroom	-2.648	.008
3. I have a comprehensive understanding of the role of the students in an inquiry classroom	-2.812	.005

**See Section 2.7.2 for explanation of Wilcoxon Signed Rank

Considering the overall group, PSTW and PSTWO's understanding of inquiry changed significantly towards a more comprehensive understanding following the

TEP (Appendix C: Tables C.10 & C.11). Following the TEP, all country cohorts form a cluster and are approximately equidistant from the notional ideal. Initially before the TEP, the PSTWO group are somewhat further from the ideal than the PSTW group (Figure 4.8). Following the TEP the PSTWO are still further from the ideal than the PSTW, but the PSTWO now have a greater understanding of inquiry than the PSTW did before the TEP.

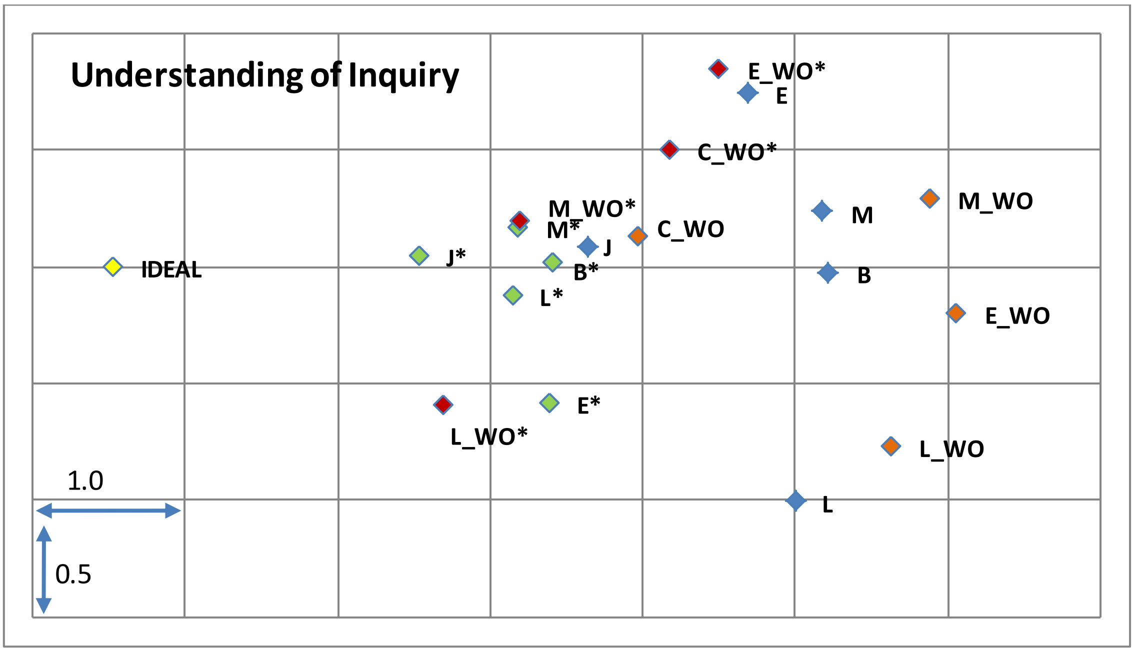


Figure 4.8: PSTW and PSTWO Changes in Understanding of Inquiry – MDS Analysis
where WO indicates a PSTWO cohort and *relates to the cohort following TEP

It is clear from Figure 4.8 that PSTW initially began closer to the ideal response than PSTWO. Following the TEP however, the PSTW and PSTWO shifted towards an understanding of inquiry that was closer to the Ideal response. E_WO and L_WO made large shifts towards the ideal, as did B, E, L, and M. Figure 4.8 highlights that participants can have a comprehensive understanding of the nature of an inquiry classroom, irrespective of their classroom experience following an inquiry and inquiry assessment TEP. However, those with teaching experience still have a significantly more comprehensive understanding of inquiry than those without teaching experience as it is clear that B*, E*, J*, L* and M* have all shifted closer to the ideal, whereas not all PSTWO cohorts have shifted to the same extent (Appendix C: Table C.12).

4.4.2 Understanding of Assessment in Inquiry

Following the TEP, the Irish group indicated a significantly greater understanding of the nature of assessment in an inquiry classroom. This change can be seen in Table 4.11 and Figure 4.9. This greater understanding highlights the suitability of the approach taken in this TEP for developing PSTs' understanding of assessment in inquiry. They did not change in all aspects of this factor however. Teacher change is slow and does not occur overnight. While some changes have been seen, developing understandings in assessment in inquiry may be a slow process.

Table 4.11: Significant changes in Irish PSTs' Understanding of Assessment in Inquiry

Statement	Z	P
5. I have a comprehensive understanding of the nature of assessment in an inquiry classroom	-3.087	.002

Considering the overall group, both the PSTW and PSTWOs' understanding of inquiry assessment changed significantly towards a more comprehensive understanding following the TEP and this is clear in Figure 4.9 (Appendix C: Tables C.10 & C.11).

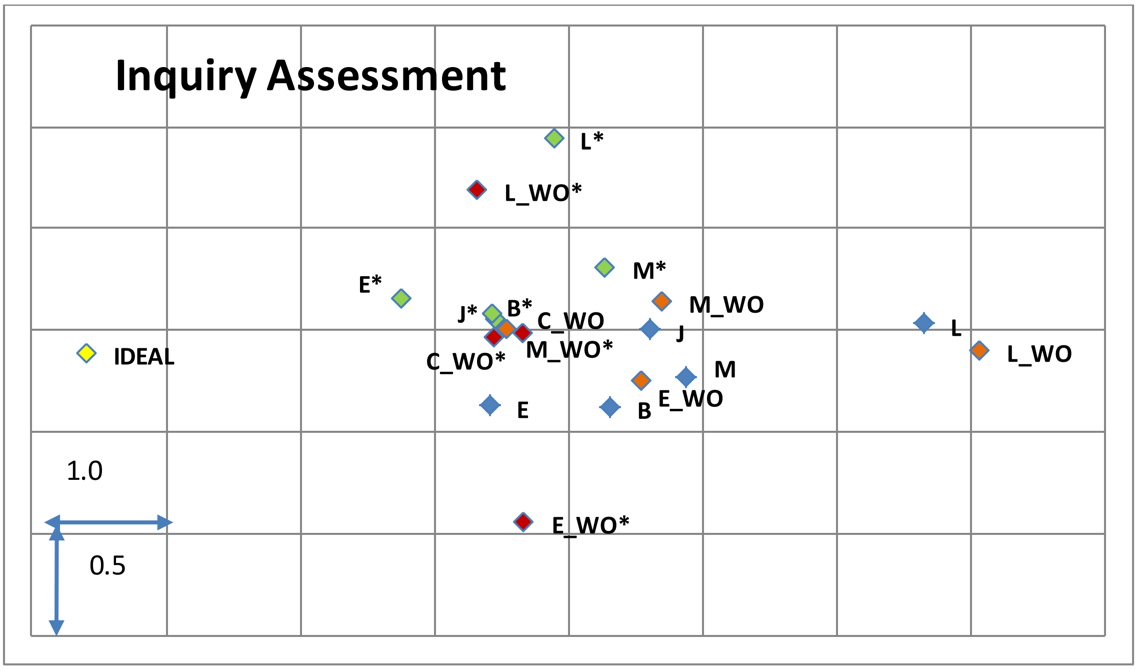


Figure 4.9: PSTW and PSTWO Changes in Understanding of Inquiry Assessment – MDS Analysis
where WO indicates a PSTWO cohort and *relates to a cohorts position following TEP

The graph demonstrates that following the programme, both PSTW and PSTWO cohorts shifted towards the Ideal. As with the results of the initial questionnaire, there were no significant differences between the PSTW and PSTWO following the TEP in their understanding of assessment in inquiry. From Figure 4.9 it can be seen that both PSTW and PSTWO cohorts provided similar responses following the TEP, for example B*, J*, C_WO* and M_WO*. PSTs' prior teaching experience has no impact on their overall understanding of inquiry assessment.

4.4.3 Confidence assessing

Following the SAILS TEP, the Irish PSTs became significantly more confident assessing three practices found within an inquiry classroom (Table 4.12). They are now more confident assessing students designing their own procedures for investigations which was an area that the PSTs did not practice and were not confident assessing prior to the TEP. They are also more confident assessing whether students understand why the data they are collecting is important, and students critiquing information from other sources, which was a practice the Irish PSTs appeared to be particularly unfamiliar or unconfident with.

Table 4.12: Significant changes in the Irish PST confidence assessing

Statement	Z	P
18. Students design their own procedures for investigations.	-2.545	.011
23. When conducting an investigation, students understand why the data they are collecting is important.	-2.138	.033
29. Students critique information from other sources, e.g. newspapers, web links, magazines	-2.012	.044

Considering the overall cohort, both the PSTW and PSTWO groups were significantly more confident assessing inquiry practices following the TEP (Tables 4.13 and 4.14 for PSTW and PSTWO, respectively). The sample used in generating Tables 4.13 and 4.14 are only those who are in the matched cohort. Therefore the figures presented in the column "confident initially" differs from that presented in Tables 4.7 and 4.8 previously.

Table 4.13: Significant changes in PSTW confidence assessing

	Confident initially	Confident finally	PSTW- sig. changes	
	%A/SA	%A/SA	Z	P
16. Students formulate questions which can be answered by Investigation	30.8%	51.6%	-3.809	.000
17. Time is devoted to refining student questions so that they can be answered by investigations.	23.1%	38.5%	-3.074	.002
18. Students design their own procedures for investigations.	33.0%	60.4%	-3.803	.000
19. Students engage in critiquing the procedures that are used when they conduct investigations.	28.6%	45.1%	-3.239	.001
20. Students conduct their own procedures of an investigation.	29.7%	56.0%	-3.933	.000
21. Each student has a role as investigations are conducted	41.8%	64.8%	-4.081	.000
22. When conducting an investigation, students determine which data to collect.	23.1%	53.8%	-5.377	.000
23. When conducting an investigation, students understand why the data they are collecting is important.	30.8%	62.6%	-4.947	.000
24. Students analyse their own data.	47.3%	63.7%	-3.317	.001
25. Students develop their own conclusions for investigations.	51.6%	75.8%	-3.518	.000
26. Students consider a variety of ways of interpreting evidence when making conclusions.	29.7%	51.6%	-4.051	.000
27. Students justify their conclusions.	53.8%	78.0%	-4.244	.000
28. Students present their results and conclusions from an investigation.	50.5%	79.1%	-4.517	.000
29. Students critique information from other sources, e.g. newspapers, web links, magazines	28.6%	48.4%	-3.853	.000
30. Students have opportunities to talk and listen to each other, in the inquiry classroom.	39.6%	51.6%	-2.940	.003
31. Students have opportunities to develop empathy with peers, in the inquiry classroom.	29.7%	35.2%	-2.450	.014

A/SA = agree/strongly agree

Table 4.14: Significant changes in PSTWO confidence assessing

	Confident initially	Confident finally	PSTWO sig. changes	
	%A/SA	%A/SA	Z	P
16. Students formulate questions which can be answered by Investigation	38.1%	58.3%	-4.255	.000
17. Time is devoted to refining student questions so that they can be answered by investigations.	41.7%	61.9%	-3.089	.002
18. Students design their own procedures for investigations.	54.8%	81.0%	-3.931	.000
21. Each student has a role as investigations are conducted	64.3%	73.8%	-2.264	.024
22. When conducting an investigation, students determine which data to collect.	57.1%	72.6%	-3.060	.002
23. When conducting an investigation, students understand why the data they are collecting is important.	60.7%	79.8%	-3.431	.001
24. Students analyse their own data.	69.0%	81.0%	-2.084	.037

A/SA = agree/strongly agree

PSTW changed significantly on 16 of the 17 items in this factor in comparison to the shifts in seven items by the PSTWO. From Figure 4.10, which shows the MDS of the change in confidence assessing of the PSTW and PSTWO, it is clear that PSTWO did not change to the same extent as PSTW following the TEP. Figure 4.10 shows a clear movement of PSTW cohorts B, E, J, L and M shifting towards the ideal. However, following the TEP, the PSTWO were still significantly more confident than the PSTW (Appendix C, Table C.12)..

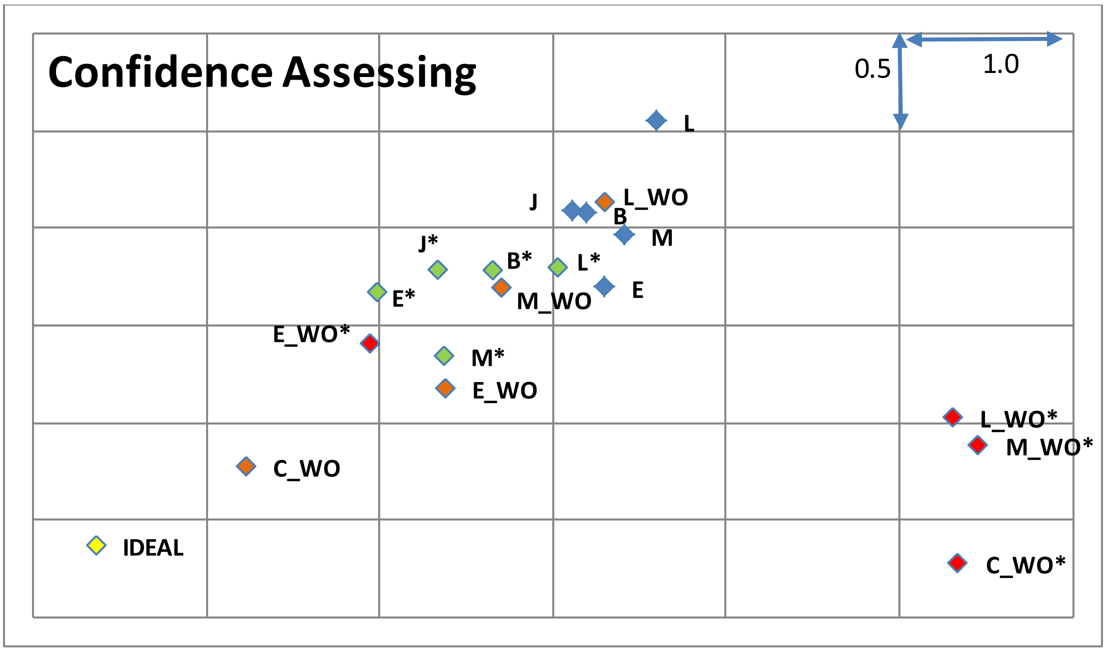


Figure 4.10: PSTW and PSTWO Changes in confidence assessing– MDS Analysis
where _WO indicates a PSTWO cohort and *relates to a cohort following TEP

4.4.4 Views on Student Learning and Feedback

Following the TEP, the PSTWO now agree more that feedback helps students decide what to include or exclude in their work and that feedback is a two-way process between the students and the teacher. After taking part in the SAILS TEP which included in-class feedback and peer assessment, both the PSTW and PSTWO agree more that quality feedback happens in the classroom during interactions with students and that peers are the best form of feedback (Appendix C: Tables C.10 & C.11).

4.5 Overall Conclusions

This study has examined PSTs' understanding of inquiry assessment, their inquiry assessment practices and confidence assessing these practices. Several lessons have been learned from this study which can aid in the development of future PST TEPs.

4.5.1 Overall group

Importantly, the results from this chapter confirm the results of Chapter 3 showing that PSTs have knowledge deficiencies in inquiry methods. However, this study has demonstrated that PSTW have a greater understanding of inquiry than PSTWO, perhaps because prior classroom experience may have allowed the PSTW to develop a greater understanding of what the methodology may look like.

This study has shown that there are deficiencies in PSTs' understanding of assessment in inquiry, in addition to inquiry itself. Many are uncertain that they could highlight the strengths and weaknesses of student work, or if they are confident using multiple assessment methods. The PSTs have similar understandings of assessment in inquiry, irrespective of their prior classroom experience. Similar to results obtained in Chapter 3, following a TEP where the focus was on experiencing inquiry and inquiry assessment first hand, the PSTs developed a greater understanding of inquiry and assessment in inquiry. The approach of experiencing inquiry and inquiry assessment first hand in the role of the student can be adapted for use within future PST modules.

Both the PSTW and PSTWO hold similar views on the most and least important practices, with the exception of PSTWO placing little importance on critiquing the procedures that are used when conducting investigations. Within their classrooms, the PSTW provide limited opportunities for students to develop their own research questions and procedures, and to determine what data to collect. This indicates that the PSTs are not completely comfortable with students having control over their own learning in the classroom. The focus of the PSTWs' assessment appears to be on what is easier to assess. As in Chapter 3, the PSTs don't recognise assessment opportunities in terms of the thinking processes in inquiry. Often their assessment focusses on outcomes rather than processes, which are also of value.

Interestingly, the practices that PSTW are carrying out are likely to be what they are assessing and what they are confident assessing. If their confidence is a barrier, then by developing the confidence of PSTW in assessing these practices, they may begin to carry out more practices in their classrooms. Focus should be placed in future TEPs on assessment practices of inquiry in addition to inquiry practices.

When comparing the PSTW to the PSTWO, the PSTWO were significantly more confident with assessing these practices in their future classrooms than the PSTW are currently, despite their inexperience. However, both they and the PSTW were least confident with assessing students formulating and refining questions which can be answered by investigations. It is clear that PSTs need support developing their skills at generating and supporting student questions which can be answered by investigations. The SAILS TEP was successful at increasing the confidence of both the PSTW and PSTWO groups when assessing inquiry practices, meaning that the approach is equally suitable for those with and without prior teaching experience. However, the PSTWO are still more confident with assessing these practices. The PSTWO are more open than the PSTW to the possibilities of looking at a range of assessment opportunities.

Overall the PSTs recognise the value of feedback on student learning. However, many are uncertain about the benefits of peer feedback, which may be due to the PSTs not being convinced that they can assess their own work, and the work of others, effectively (van Gennip, et al., 2010). The PSTWO group were more likely to believe that feedback should benefit students' ego. This can be damaging to the self-esteem of low achievers, and can be particularly damaging to students' motivation and learning in high-stakes environments (Black, et al., 2003).

After taking part in the SAILS TEP which included in-class feedback and peer assessment, both the PSTW and PSTWO agree more that quality feedback happens in the classroom during interactions with students and that peers are the best form of feedback. This indicates that the SAILS TEP was successful at highlighting the benefits of various methods of feedback and formative assessment and the approach should be maintained for future TEPs.

4.5.2 Irish Sample

Prior to TEP the Irish sample did not differ significantly from the European sample in their understanding of inquiry and assessment of inquiry. The most assessed practices by the Irish PSTs were that each student has a role as investigations are conducted, that students develop their own conclusions, and understand why the data they collect is important.

In terms of the confidence of Irish PSTs, they are most confident assessing that each student has a role as investigations are conducted, students are analysing their own data and that students develop their own conclusions.

The Irish PSTs are more positive about the benefits of feedback on students' learning than their European counterparts. They were also significantly less likely to believe that quality feedback happens interactively and immediately in the classroom while students are learning.

After the TEP, the Irish PSTs showed significantly greater understanding of the nature of assessment in an inquiry classroom and expressed significantly more confidence assessing and providing feedback within an inquiry classroom.

4.5.3 Implications

This phase of research showed that PSTW have a greater understanding of inquiry than PSTWO. Therefore in future TEPs when dealing with PSTWO, every effort should be made to incorporate either some form of teaching practice, or the PSTWO should reflect on the teaching carried out within the TEP and what they might do.

This study showed that the practices that PSTW are carrying out are likely to be what they are assessing and what they are confident assessing. Focus should be placed in future TEPs on assessment practices of inquiry in addition to inquiry practices.

It is clear that PSTs need support developing their skills at generating and supporting student questions which can be answered by investigations as this was an area not practiced or assessed to the same extent as other skills. This is a skill that should be incorporated into future inquiry TEPs so that PSTs can attempt to develop their own questions while receiving support.

For TEPs incorporating assessment and feedback, effort should be made to ensure that participants are made aware of the potential issues relating to feedback benefitting students' ego.

The Irish TEP was suitable for developing PSTs' understanding of inquiry and assessment in inquiry, but future TEPs will need to provide PSTs with opportunities to trial or develop IBSE and assessment activities during their TEP to increase their confidence in assessing a wider variety of practices.

It is important to be mindful that teacher change is slow and does not occur overnight. While some changes have been seen in this phase of the study, developing understandings and changing practice is a slow process and it is positive to have seen some changes. The aim in any pre-service programme would be to sustain these changes over the duration of the course.

Chapter 5 details how some of these results and others have been used to develop a further inquiry teacher education programme aimed at pre-service science teachers.

Chapter 5 – Design of an Undergraduate Module for PST

The analysis of the data in Chapters 3 and 4 have allowed for the development of a profile of the PSTs in relation to teaching through inquiry and assessing inquiry practices. Analysis of the PSTs in these studies provides information about PSTs across Europe and the changes that focussed TEPs have on the participants. However, the challenge now is to incorporate elements from these TEPs into mainstream PST education programmes as Phase 3 of this study was to determine "How can PSTs be supported in the development of their knowledge of and views towards inquiry in an undergraduate chemistry laboratory module?"

An opportunity arose to modify a module using the lessons learned from phases 1 and 2 of this study. This chapter focusses on the design of a module for pre-service teachers, which was developed using the results of Phases 1 and 2. The aim of this module was to provide opportunities for the students to experience inquiry first-hand, learn content and develop skills through inquiry, and experience formative assessment.

A case-study approach was selected as the appropriate methodology for this study as detailed in Chapter 2. A case-study approach has been used as this study involves the design of an intervention and the monitoring of this intervention with a particular group. The participants in this study consisted of 34 pre-service physical education and biology teachers who were in the 2nd year of study. These participants have not yet carried out any formal teaching practice and have taken part in a maximum of four 6 minute long microteaching sessions. The laboratory module developed consisted of 33 contact hours over 11 weeks and was led by an academic and the researcher.

5.1 Lessons from Phase 1 and Phase 2

Analysis of the participants in Phases 1 and 2 provided useful insights for the development of inquiry teacher education programmes. Although some differences were clear between PSTs depending on the country group, most of these differences were related to their prior experience with teaching or with inquiry.

Some general trends can be extracted from these European studies that can be used to inform the development of modules for PSTs in the local context. Generally, the PSTs have a limited understanding of inquiry and inquiry practices in the classroom. This is mainly because they have probably not experienced it directly themselves as students in school, nor had the experience of using the pedagogy in the classroom. They are however conscious of time pressures in teaching the curriculum and the scope of the curriculum as issues that may hinder their implementation of inquiry. Future teacher education programmes, such as the one described in this chapter, should be cognisant of these challenges and highlight the capacity that an inquiry approach can have for achieving the aims of a given curriculum.

Interestingly, PSTs have identified practices of "good teachers" as "using student questions to guide their teaching", "allowing students to develop their own investigation or research question", and "encourage student discussion on scientific topics relevant to everyday life". These practices can be linked to inquiry practices and so PSTs are identifying good inquiry practices, even though their understanding of the methodology is not complete. Further emphasis needs to be placed on these approaches so that students feel comfortable carrying out the practices of "good teachers" and it should be highlighted that these are aspects consistent with an inquiry approach to teaching.

Additionally, PSTs have identified the positive effect of feedback on learning, recognising its role in helping students to learn and in informing the teachers' next steps in teaching and the students' next steps in learning. However, the PSTs are more unsure of the benefits of feedback that occurs "interactively and immediately in the classroom while students are learning" and of peer assessment. As such, an integral part of the developed module is interactive feedback which occurs “on-the-fly” in the classroom, as well as peer given feedback during certain activities and assignments.

Many professional development programmes are designed to attempt to change a teacher’s attitudes and beliefs towards certain methods of teaching or a new curriculum. The presumption is that once a teacher’s attitudes and beliefs have been changed, specific alterations will occur in their classroom practices or behaviour, leading to improved student learning (Fullan, 1982; Guskey, 2002). However, Guskey (2002) argues that teachers’ attitudes and beliefs will change when they have seen the benefits of a teaching approach; therefore teachers should be encouraged to address or try out new practices so they may see evidence of student learning which will ultimately change their attitudes and beliefs towards the pedagogy. This module of change was presented earlier in Section 1.4.1.

In the case of PSTs, many do not have the opportunity to try out different methodologies during their programmes. Periods of school placement can be brief or focussed on already trialled methods which they have experienced as a student and are comfortable with. Hence, for PSTs, it is important they can experience the effect of a new pedagogy on themselves as learners. With appropriate discussion around the process they may see the value of the pedagogy to themselves as learners and hence adopt the new approach in their own teaching. This is particularly important in light of the results determined from Phase 2, highlighting several differences between those participants with and without teaching experience.

This approach was also emphasised within the ESTABLISH and SAILS projects, where the PST TEP in each case involved the participants trying out the methodologies in the role of the student prior to discussion on the merits of the practices on student learning. In this manner, the PSTs were provided the opportunity to experience the approach and understand the benefits for learning, and consequently their attitudes changed. Data from Phases 1 and 2 has shown that following TEPs of the framework discussed above, PSTs’ understanding of inquiry can be increased. The PSTs generally were also uncertain of many different assessment methods and were unsure of how to assess inquiry skills. Following the SAILS TEP, PSTs' confidence in these aspects increased.

Having analysed the benefits of the TEP intervention programmes on PSTs, the challenge is now to model the implementation of these key ideas into a science module, currently delivered to a PST group.

5.2 Context for Module

The participants chosen were selected as they were a convenient sample consisting of thirty four 2nd year undergraduate pre-service teachers. These PSTs will ultimately be qualified to teach biology and physical education to Leaving Certificate level and science (chemistry, physics and biology) to lower second level. The majority of this cohort had not studied chemistry at senior cycle at 2nd level, and some may not even have studied science at junior level. As such, it can be assumed that this group of PSTs have minimal knowledge and understanding of chemistry prior to their participation in this module. Also of note is the fact that these PSTs have not had any teaching experience before completing this module. Their required teaching placements take place after they have completed this module.

The module selected for this study consisted of 11 three hour laboratory sessions run over 12 weeks. This module was chosen as it was a chemistry module which is a subject that the chosen cohort is unfamiliar with. This was important as the PSTs were to experience inquiry first-hand in the role of the student, and this would be achieved best with an area that is new to them. Additionally, the background of the researcher is in the field of chemistry so the researcher could take on an active role within the laboratory module and appropriately design activities and assessments.

5.3 Framework for Design of Module

The aim of this module was to provide opportunities for the students to experience inquiry first-hand, learn content and develop skills through inquiry, and experience formative assessment. To achieve these aims, the module should provide opportunities for the students to experience inquiry first-hand, learn content and develop skills through inquiry, and experience formative assessment.

Prior to the implementation of the module, the approach taken needed to be decided upon and what aspects should be focussed on over the course of the module. As such, a framework was developed to highlight 6 key aspects that were to be addressed within the module. These aspects were then emphasised in what the learner was doing (experiencing) or were taken into account in the design of the specific activities. These aspects are given in Table 5.1, and the rationale for the inclusion or focus of each aspect is discussed in a section below.

Table 5 1 Framework for Development of PST Chemistry Module

Emphasis	Aspect	Section
Learner	Experience collaborative laboratory work	5.3.3
	Experience inquiry as a learner	5.3.4
	Learn chemistry content knowledge	5.3.6
Activities:	Integrate visualisations and modelling	5.3.1
	Tackle alternative conceptions in teaching	5.3.5
As PSTs	Address their views of science and school science	5.3.2

5.3.1 Visualisations/ Modelling

The use of visualisations or representations of phenomena in chemistry was chosen as a focus within this module primarily because the cohort participating had a limited understanding of chemistry prior to the implementation of the module. As they would eventually teach chemistry to their students it is clearly important that they themselves have a deep understanding of the subject area.

Johnson's triangle (Johnstone, 1991) focusses on three levels of chemistry – the macroscopic, sub-micro, and symbolic. As chemists we can seamlessly move between each level e.g. water as liquid, vapour or solid to molecules of water to symbols $H_2O(g)$, $H_2O(l)$, $H_2O(s)$. However, the nature of these changes can be difficult for novice learners. One way to address this is to make explicit the interactions between these levels through visualisations and use of modelling (Johnstone, 1991)

Visualisations can help students to understand concepts within chemistry. Geelan et al. (2014) suggest using images and visualisations to help students to develop mental models so that they may cultivate an understanding of propositional representations such as definitions, symbols and formulae.

Wu and Shah (2004) recommend five principles for designing chemistry visualisation tools to help students understand chemistry concepts and develop representational skills through supporting their visuospatial thinking. The principles they suggest are:

1. Providing multiple representations and descriptions;
2. Making linked referential connections visible;
3. Presenting the dynamic and interactive nature of chemistry;
4. Promoting the transformation between 2D and 3D;
5. Reducing cognitive load by making information explicit and integrating information for students.

In addition to the development of a deep understanding of chemistry, an emphasis on visualisations was included in this module as it could be used for diagnosing any specific issues that students have in particular areas of chemistry. If students create their own visualisations representing their knowledge and views of concepts, instructors can easily identify any faulty understandings they may have. Therefore, activities focussed on visualisations were included in the module and students needed to be given opportunities to draw their own mental models.

5.3.2 Address views of school science/ science

From the international ROSE project (Jenkins & Pell, 2006), many students in developed countries do not have a positive view of school science, despite students' positive views about science and technology. Research on the nature of science (Lederman, 1992) has indicated that students focus on science as being a fixed body of knowledge with known answers to questions. The view that science, particularly school science, is viewed as a set of unrelated facts that students commit to memory in one that needs to be addressed at all levels of teacher preparation. Inquiry activities can be useful for providing a range of opportunities to address these issues, such as experiments where there is no one correct answer or method, but various suitable methods and answers. Throughout the module, it is important then that opportunities are presented for students to address these issues.

5.3.3 Experience collaborative laboratory work

It has been previously identified that "*students can be successful in their laboratory class even with little understanding of what they are actually doing*" (Johnstone, et al., 1994). This mode of laboratory activity is unlikely to encourage the deep content knowledge, beliefs and attitudes about science teaching that are desirable. Laboratory classes traditionally involve students carrying out experiments where the procedure is provided and the results are known in advance. Very little thought is required of the students who can passively carry out the provided instructions. These types of classes have been referred to as "recipe" labs (Domin, 1999; Kelly & Finlayson, 2007; Lovatt, 2009). Therefore, as much as possible, the laboratory sessions in the new module were conducted through the methodology of inquiry which aligns more with the attributes desired. The activities were designed to give students opportunities to make their own observations, plan their own investigations and draw their own conclusions.

Lazarowitz & Tamir (1994) and Lunetta (1998) have previously suggested that laboratory activities have the potential to support collaborative social relationships in addition to cognitive development and improved positive attitudes towards science. The informal atmosphere of laboratory activities and the increased opportunities for interaction between the students themselves and their teacher can promote a healthy learning environment which is conducive to inquiry and collaborative learning. Therefore the activities within the module were designed so that both individual and group work were incorporated and discussion and interaction was considered very important within these activities.

Another important aspect of experiencing laboratory work for these particular participants is to learn how to handle materials safely. The participants are inexperienced with chemistry so it would not be wise to send them out to teach chemistry in schools without practical experience handling chemicals, glassware, etc.

5.3.4 Experience inquiry as a learner

It has been show that TEPs where teachers are immersed in authentic inquiry will more likely enhance teacher knowledge, prepare teachers to implement inquiry instruction, and lead to enhanced student understanding (Capps & Crawford, 2009). The results from Phase 1 show that developing PSTs' understanding of inquiry is achievable in a TEP where they experience inquiry first hand. The greater the PSTs' understanding of inquiry, the more they would consider inquiry as their main teaching method in future. Phase 2 highlighted PST's particular lack of confidence assessing students formulating and refining questions which can be answered by investigations. It is clear that PSTs need support developing their skills at generating and supporting student questions which can be answered by investigations. In light of this, developing researchable questions was a focus within the laboratory activities. To provide the participants with as full and comprehensive a view of inquiry learning as possible and immerse them as much as possible, it is suggested that different lab sessions focus on the utilisation and development of different inquiry skills. The particular skills to be emphasised in this module were:

- Developing researchable questions/ hypotheses;
- Planning investigations;
- Critiquing experiments;
- Forming coherent arguments; and
- Debating with peers.

5.3.5 Alternate conceptions in teaching

Alternate conceptions or misconceptions are essentially wrong or flawed ideas that can impede learning and when not addressed can result in further defective conceptions (Gurel, et al., 2015). These are problematic for students, but the issue becomes more serious when the person holding the misconception is going to be a teacher, where they may pass on their incorrect notions to their students. As such, it is imperative that we identify and address misconceptions that the PSTs taking part in this module have. Potential misconceptions from various topics within chemistry shall be addressed within the labs using approaches such as cognitive conflict.

Misconceptions could be dealt with “head on” where particular activities can be developed aimed at addressing specific misconceptions. These would be misconceptions that have been identified in the literature, and therefore specific activities can be designed in advance to deal with these issues before students present with them (Longfield, 2009).

Additionally within the lab there are opportunities for various misconceptions to be identified as part of lab work and assessments, so these can also be addressed.

Activity-based and inquiry methods have been shown to be appropriate methods for addressing misconceptions as an approach where students have more control of their own learning increases the likelihood that students will challenge each other’s, or their own, misconceptions. This is thought to be more beneficial to students than having their ideas challenged by the teacher (Longfield, 2009; Goldsmith, 2006). Discrepant events or cognitive conflict, where the outcomes of an activity are not expected by the student based on their misconceptions, encourages students to think through their misunderstandings, which is more beneficial to students than a teacher simply telling them the correct answer (Longfield, 2009). As such, activities within the module are included where there are results that students with particular misconceptions will not expect.

5.3.6 Content

Due to this particular cohort’s minimal background in chemistry, a particular focus on content was deemed necessary. Of additional importance is ensuring that much of the content covered within the module should link to the learning outcomes of the new Junior Certificate Science course. This is important as the participants need to be prepared for teaching chemistry in their undergraduate teaching placement and future teaching career.

The main chemistry topics to be covered within the laboratory module were:

- Separation techniques – including filtration, chromatography, distillation;
- Preparation of gases (O_2, H_2 and CO_2);
- Identification of anions and cations;
- Identification of acids and bases, and development of pH scale;
- Synthesis of an organic compound and its identification and purification.

Focussing on content has an additional importance in this module. Previously, Zion et al.'s work (2007) showed that teachers' lack of scientific knowledge was a barrier to inquiry teaching as the teachers felt that they could not facilitate their students in a topic that they are not proficient in (Zion, et al., 2007). An adequate grasp of content knowledge was also found to play a key role in whether or not beginning teachers implement inquiry successfully. Without a good standard of content knowledge, beginning teachers will rely on textbooks (Roehrig & Luft, 2004).

The results from Phase 2 showed that PSTs don't feel that they have sufficient knowledge of science to implement an inquiry lesson effectively. Those that feel they have insufficient knowledge are unlikely to know how to ask students higher order questions or be comfortable asking questions where they are unsure of the answer themselves. A focus on developing PSTs' content knowledge needs to be a focus to address these issues.

5.4 Design of Activities

As previously discussed, the aim of this module was to provide opportunities for the students to experience inquiry first-hand, learn content and develop skills through inquiry, and experience formative assessment as part of Phase 3 of this study. This was to be done within a lab which provided opportunities for the students to experience inquiry first-hand, learn content and develop skills through inquiry, and experience formative assessment. A framework has been developed detailing six aspects which should be focussed on within the laboratory module. Activities have been designed which incorporated these aspects. How these aspects have been dealt with or incorporated into the activities shall be discussed. See Table 5.2 for the full list of activities.

The activities that have been chosen and developed for this module were selected for the scope they provided for dealing with these six aspects. Although some of these aspects were embedded into many of the activities, not every activity tackled all six aspects. The focus shifted from week to week. Each aspect shall be discussed in greater detail and examples described of the activities which dealt with these core features.

5.4.1 Visualisations/ Modelling

As discussed in Section 5.3.1, the use of visualisations can be beneficial for the development of students' understanding of science. Additionally, visualisations can be used to identify problems that students may have in their understandings which can be addressed in the laboratory.

Due to the participants' inexperience with chemistry and the importance of visualisations, it was considered important to emphasise this practice from the beginning of the module, paying particular attention to it in the first few weeks.

The first activity carried out within the laboratory module was designed to be purely a visualisation task. Initially, the first undertaking involved the students drawing a picture of a football pitch. Discussion would then follow about how drawings are not actually football pitches, but simply a representation of a pitch. Next, the focus would move on to considering representations moving from a macro level to a molecular level. Students are asked to draw a container partially filled with liquid. The instructor would then ask the students to consider what each phase in the drawing (solid container, liquid in container, gas in container above the liquid) looks like at a molecular level. This can be used to help students consider the differences between solids, liquids, and gases at a molecular level and to identify any misconceptions the students have about states of matter and address them.

The instructor would next ask the students to consider what would happen when the liquid in the container begins to boil. This is important as it allows for the instructor to see what the students believe is occurring when substances move between states and for misconceptions to be identified and addressed. The students should then try to represent this state change at a molecular level. The instructor should not tell the students what to draw. To guide the students, the instructor should ask the students to consider the differences between solids and liquids and consider how this is reflected at a molecular level. The instructor can use this to identify issues such as representing bubbles of "nothing" or "air" rather than gaseous water and bonds breaking when boiling.

In the second week of the module, the content focus shifts to separations and an understanding of how the properties of substances are exploited to achieve separation. Various activities are carried out within the domain of separations, including the coffee and tea activity. One of the main aims of the coffee filter activity is to model what is happening at a molecular level when substances are separated using a filter. To begin a tea bag is placed in water and subsequently the tea is poured through filter paper. Next, muddy water is poured through filter paper. The students would see that tea leaves are kept in the filter paper, but a brown liquid comes through. The students must consider what is in the brown liquid and why did the filter paper not stop these materials. At this point the students are asked to model why 'tea' passes through the filter, but 'mud' will not pass through the same filter. The students should be guided to consider what is happening at a level that they cannot see, and to consider the properties that are allowing these processes to take place. Here they are again moving from a macro level to a molecular level of visualisation.

5.4.2 Address Views of School Science/ Science

An important focus of the lab in terms of participants' views of school science and science is highlighting that science is not all about right answers. The approach taken in this session was to challenge the participants' views of science through the use of cognitive conflict.

The first activity where students witnessed something unexpected which did not fit with their current views of science was an activity where iodine passes through different membranes which the students would have assumed to be impenetrable to liquids. Students follow the guidelines provided for setting up their membranes (gloves, clingfilm, etc.), starch and iodine solution, including a control. This was done by placing starch into a vial, a membrane placed over the top of the vial, and iodine is then placed into the membrane at the top. It may be useful to discuss what we use the different membranes for, any experience they may have had with liquids "appearing" around these membranes, and to have students look up the size of different atoms and molecules. In addition to the cognitive conflict, students should create representations for what is occurring at a molecular level to describe what they understand to have happened.

In the third session of the laboratory module, the students take part in another activity which includes a focus on cognitive conflict. In pairs, students are provided with a combination of substances that they must record the mass and volume of individually, and then predict what these values will be once the substances have been mixed together. Students should be encouraged to have a reason for their predictions, otherwise they are meaningless. The students should then mix their substances and rerecord the mass and volume of their substances. Many of the mixtures will provide surprising results which may contradict with their predictions and students should be asked to consider why they obtained the results that they did. Each group will explain to the rest of their class what results they obtained and as a class, students can discuss their unexpected results and draw conclusions on what is occurring. Guide the students to sensible conclusions with questioning about what is occurring in each case at a molecular level.

All of the inquiry activities have many different ways of setting up the investigations and therefore the range of answers determined may be varied. However within the parameters set out, these results may be correct. Activities such as reaction rates or SAP will generate much discussion on the range of investigative techniques that can be used and hence the range of values, depending on the technique, that are valid for the criteria stated.

5.4.3 Experience Collaborative Laboratory Work

The participants worked collaboratively in the majority of the activities that they participated in. Typically when the students worked in groups they worked in pairs, but they also worked in groups of fours for certain activities.

There are several different activities within this module where the students had the opportunity to deal with specific substances where they needed to practice safe handling of materials. Over the fifth and sixth lab sessions the students must identify anions and cations using standardised tests and then identify unknown compounds using these tests and solubility rules. Over the course of this laboratory work, the participants must learn how to carefully deal with concentrated acid during the brown ring test, and how to safely carry out flame tests so that they may identify their unknown compounds.

An activity focussed on handling apparatus and chemicals safely, involved the synthesis of aspirin. This involved the synthesis, purification and confirmation tests of aspirin. This was an important experiment for the development of students' lab skills as many have never synthesised an organic compound before. As such, they are learning how to set up and handle appropriate glassware for refluxing and distillation, in addition to vacuum filtration, all of which will be mainly new to these participants. They will again have the opportunity to use concentrated acids and must also learn how to handle and dispose of solvents appropriately. Following synthesis students should purify the product, carry out TLC and determine the melting point of their product to determine purity. In preparing melting point tubes they will have to deal with broken glassware, and will therefore be required to dispose of glassware in the appropriate bins which is an important aspect of safety within a laboratory.

The final lab focusses on the microscale preparation of oxygen, hydrogen and carbon dioxide, and then investigation of their properties. Students prepare gases in syringes, thus investigating relative quantities of reagents. They also investigate the properties of these gases, including their relative densities, reactivity, acidity, and combustion reactions. In addition to the various lab skills required to carry out these activities effectively, the students are exposed to safe handling of flames, and also gas pressure.

5.4.4 Experience Inquiry as a Learner

While not all of the activities included within the module were taught through inquiry, the overall approach taken in running the lab was quite different than in traditional laboratory modules. Some key aspects of the approach adopted in the lab were that the participants were given a certain amount of autonomy where they could develop their own methods as well as their own conclusions. Discussions would take place during or following these activities to guide and probe participants towards interpretation of the evidence. The sessions were quite reactive and were often dictated by discussions which occurred within the laboratory.

During the second week of the laboratory module, the students carry out a range of activities under the topic of separations. A separation activity was carried out in such a way that the students experienced inquiry as a learner. The primary aim of this activity is to introduce the students to the process of planning their own experiments and critiquing them. When given a container with a mixture of seeds, students were asked to develop a plan (typically in pairs) to separate these seeds into their respective types. However, the students are not allowed to touch the seeds by hand.

Students are allowed to trial their plans, identify issues, re-plan their separation and try again. When groups have trialled their methods, groups are brought together to discuss what methods have been used and what property they have exploited to separate their seeds. This activity also focussed directly on identifying the property of the mixtures that was used to facilitate separation, hence prioritising the process rather than the result.

Another example of an inquiry experiment that was incorporated within the module is the SAP activity. As part of this activity, the students focus on planning an investigation using a material that they are unfamiliar with. As they are unlikely to have encountered super absorbing polymers (SAP) directly, a demonstration on their purpose and abilities is useful at the beginning of the activity. Students are asked to consider how much liquid a nappy (containing SAP) can hold without leaking. As estimates will probably be quite conservative, measured amounts of water can be poured into a nappy until it can no longer hold any more. Following the demonstration, students are asked to design an experiment to determine the absorbency of SAP. Students should trial their plan and it will quickly become apparent that they cannot properly plan an experiment having never "played" with the material before. Students are unlikely to have considered what the end point of the experiment would be or how they will accurately measure what has been absorbed. At this point students should identify problems in their plan and design a new experiment, hence giving focus to the skill of critiquing experiments. Students are brought together to discuss their plans, problems, and how they decided on their end point. As a further investigation, students should be asked to design an experiment to determine if the absorbency changes if solutions other than water are used, such as urine. Here they must consider what is different between urine and water and how these differences might impact the absorbency of SAP.

During the eighth laboratory session, the students are tasked with a Separation Challenge. The primary focus of this activity is for students to appropriately plan separation experiments based on properties of substances, and to critique their experiments when the desired results are not obtained. As the students have had experience with separating mixtures and planning their own investigations at this stage, the students are given minimal assistance over the course of this activity. In pairs, students should be provided with a mixture containing several different components and asked to separate them. The mixtures should require several different separation methods to obtain pure samples of each component. An example of a suitable mixture is sand, iron filings, candle wax, and garlic granules. The students generate and implement a plan to separate the mixture into its individual components. When students encounter difficulties along the way, the instructor won't provide an answer, but may ask students to identify a property of one of the substances which could be exploited for the purpose of separation. The students separate at least two different mixtures over the course of the lab and identify the property used to separate each component within these mixtures.

5.4.5 Alternate Conceptions in Teaching

Alternate conceptions, or misconceptions, in teaching have been highlighted in Section 5.3.5 as an area of major importance within this module for several reasons. As such, this is an aspect that was embedded within all of the laboratory sessions. During all of the activities an aim was to identify any alternate conceptions that are held by the participants. Following the identification of misconceptions held by the participant(s), the instructor can introduce some aspect of cognitive conflict or an additional activity/experiment aimed at guiding their learning and exploring the concept.

Although not a laboratory activity, students were assigned a misconceptions task. During the course of the module each participant was provided with an individual concept cartoon, either from Naylor & Keogh's (2000) work, or a cartoon of the researchers' design (examples of these are shown in Figures 5.1 and 5.2, respectively). The researcher designed these cartoons based on various misconceptions that have been identified within the chemistry education literature. The researcher designed relevant comments that students may make based on alternate conceptions they may hold, and then designed an appropriate graphic for each set of misconceptions. The participants were given the task of identifying and discussing each of the misconceptions highlighted in their cartoons. They then had to describe how they would teach their students the given topic in such a way that their students would not develop these misconceptions.

5.4.6 Content

The content within this module was typically dealt with through an inquiry approach. However, some sessions focussed more heavily on the development of content knowledge than others. During the fifth and sixth sessions when participants were learning to identify anions and cations experimentally, there was an emphasis placed on students learning about ions, charges, their reactions, and how to write reaction equations. This content area features prominently in the curriculum that they will eventually teach and it forms the foundation of much of chemistry, so it was integral that students developed an understanding of this area over the course of the lab.

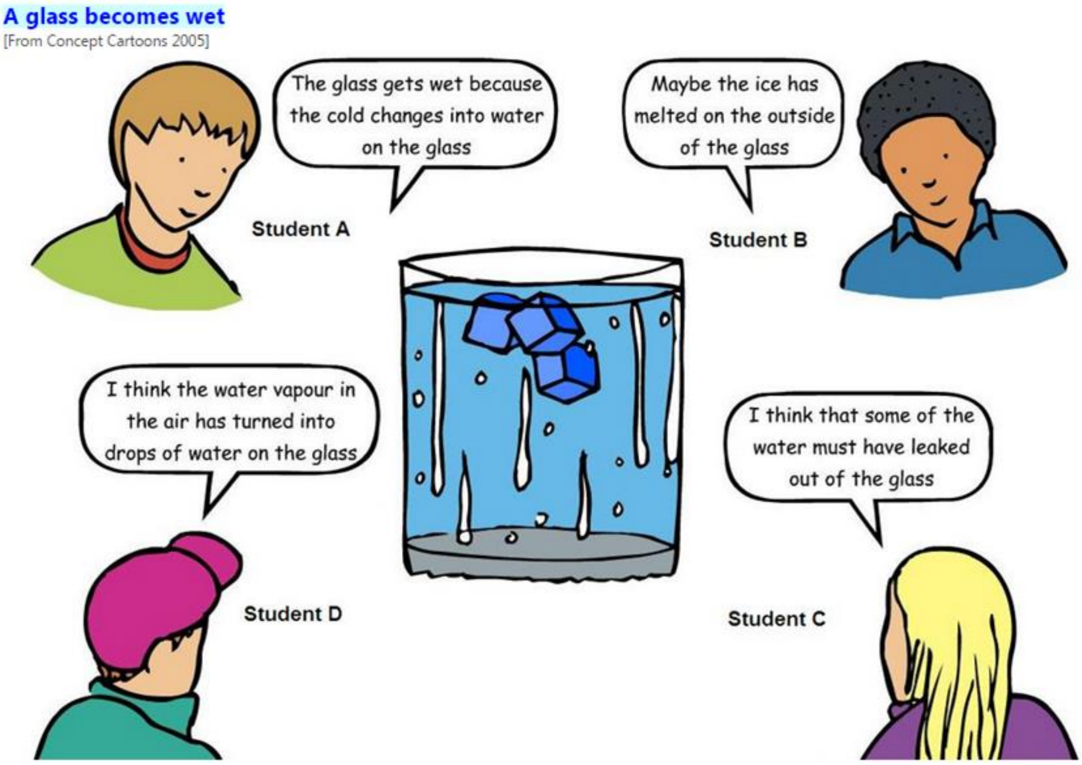


Figure 5.1: Example of Concept Cartoon from Keogh and Naylor (Naylor & Keogh, 2000)

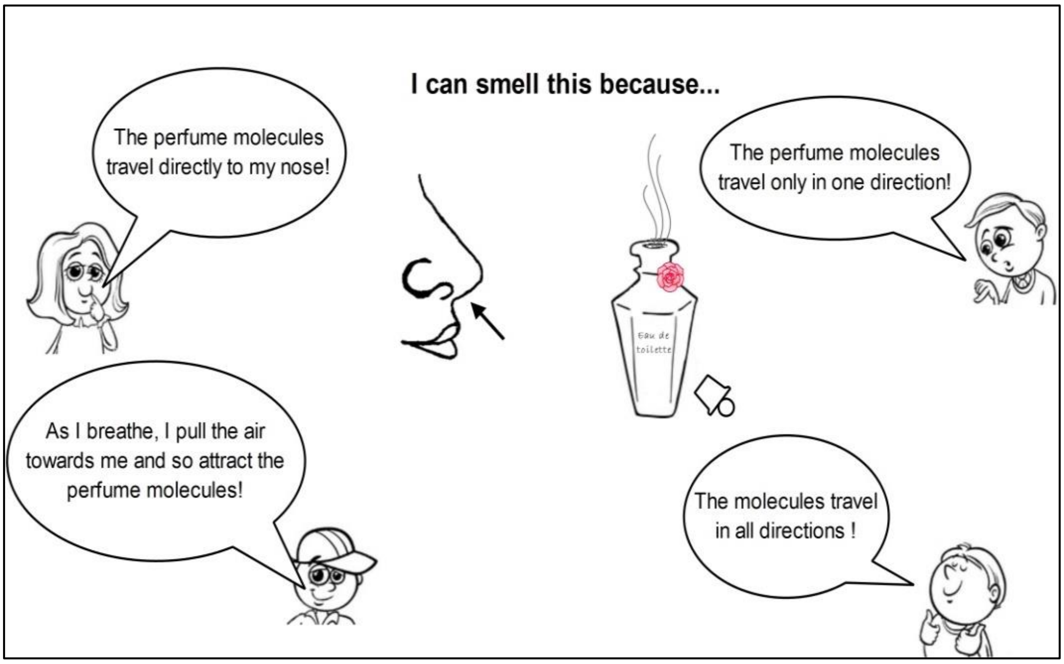


Figure 5.2: Example of researcher designed concept cartoon

In the seventh session of the module, the participants learned about the topic of acids and bases, which constitutes another major section of the chemistry course the students would eventually teach. This section built upon the previous learning developed within the anion and cation lab sessions. An understanding of the topics of acids and bases, pH, concentration, and graphing are all developed within this laboratory session.

During this activity the students classified substances based on their reactions. The students have to make and record observations, classify the information, draw conclusions on whether a substance is an acid or a base, and represent the data appropriately. The first aspect of the experiment involves the students using indicators to classify various different unknown solutions and then categorising in terms of similarity of observations. However, it is not enough that the students group them based on their reactions. Following classification, the names of the unknown substances are revealed by the instructor and the students are then asked to identify what is common to the acids and what is common to the bases. Here, the students are learning about the ions typically present in acids and bases, and how we classify these substances at a molecular level. Students then carry out a series of dilutions on acid and base solutions while accurately determining the pH values after each dilution and learning to calculate the concentration of the solutions. Students then attempt to graph their results of pH vs concentration, but due to the nature of the change in dilution, the students struggle. Under instructor guidance, the meaning of pH values can be clearly explained.

Table 5.2 gives an outline of each lab session, the content focus, and activity as well as the key skills identified for each session.

Table 5.2 Outline of the activities covered over the course of the module

Lab session	Title	Content focus	Activity	Skills	Misconceptions*
1	Visualisations	Modelling	Drawing and discussing representations at a molecular level of different states of matter, and changes of state, e.g. boiling, diffusion	Creating models	Distinguishing between liquids and solids. Vapour as 4th state of matter. There is air between atoms and molecules.
	Properties of everyday things	Classifying substances as elements, compounds, mixtures, metals, non-metals, solids, liquids, gases, and solutions.	Determined the properties, such as solubility, of various materials by using prior knowledge such as whether it is an element, compound or mixture, by mixing substances together, adding water or oil, etc. to determine	Searching for information themselves	Substances disappear when they dissolve. "In-between" solids. Solids are heavier than liquids and gases.
	Classifications		Decided on criteria to sort various materials shown on cards into groups.	Classifying and representing information	Mixtures are chemically bonded together.
2	Seed separation	Separating mixtures and modelling	Given a mixture of seeds and told they may not handle them. They planned and critiqued their experiments, and generated alternative plans as a result of identifying problems.	Planning investigations, critiquing experiments	Mixtures are chemically bonded together. Components of mixtures have different properties when mixed.
	Coffee filter		Examined and modelled why tea passes through a coffee filter but mud does not.	Creating and critiquing models	
	Membranes		After experiencing cognitive conflict when iodine appeared to pass through plastic following a positive starch test, students drew conclusions on what they thought was happening.	Drawing conclusions	Sizes of atoms/ molecules. Spaces between molecules and atoms.
	Osmosis		After adding salt to sliced aubergine the students drew conclusions on what was happening.	Drawing conclusions	

Lab session	Title	Content focus	Activity	Skills	Misconceptions
3	Evidence of a reaction	Reactions	Participants carried out a reaction which results in colour changes, temperature changes, and production of gas. They carried out several experiments, and determined what was evidence of a physical change / chemical change.	Planning investigations, drawing conclusions, observations	Chemical changes and physical changes are the same thing.
	A + B = C or AB or BA or B+A	Conservation of mass and particulate nature of matter	Participants investigated mass and volume changes following reactions. Following cognitive conflict, they drew conclusions about what happened and critiqued their experimental set ups.	Drawing conclusions	Mass changes following a chemical reaction. Gases weigh less than liquids.
4	Super absorbing polymers	Planning investigations	Designed and carried out an experiment to determine the absorbency of SAP. Following initial issues they identified problems in their plan and designed a new experiment. Designed an experiment to determine if the absorbency changes with other solutions, such as urine.	Planning investigations, critiquing experiments	
5	Is a salt soluble	Identification of anions, writing reactions	Participants carried out a series of positive anion tests so that they can identify unknown solutions.	Making and recording observations, Drawing conclusions	Reasoning about reactions does not involve particles.
6	Forensic analysis	Identification of cations, flame testing, writing reactions	Participants carried out a series of positive cations tests, including flame tests. Using the information determined from this lab and the previous lab, they worked to identify different unknown salt solutions	Making and recording observations, Drawing conclusions	Reasoning about reactions does not involve particles.

Lab session	Title	Content focus	Activity	Skills	Misconceptions
7	Acids and Bases	Acids and bases – concentrations and pH	Using indicators, the participants classified various different unknown solutions to similar results from known acids and bases. They then carried out dilutions and attempted to graph their results. They tried to neutralise “stomach acid” with drain cleaner.	Making and recording observations, classifying information, drawing conclusions, representing data.	Acids eat material and burn you. Neutralisation is the breakdown of an acid. pH can’t equal 0 Strong acids must be pH = 1-3 Strong acids eat away material faster than a weak acid. A base is something that makes up an acid. Acids and bases aren’t classified based on a particulate basis.
8	Separation Challenge	Separating mixtures	Students were provided with a mixture containing several different components. They generated and implemented a plan to separate the mixture into its individual parts.	Planning investigations and critiquing experiments	Mixtures are chemically bonded together. Components of mixtures have different properties when mixed.
9/10	Aspirin	Synthesis and product purification	Participants followed a method and carried out a synthesis of aspirin. They purified the product and carried out TLC and determined the melting point of their product to determine purity.	Lab skills	Reactions always got to 100% completion
10	Project critique		Participants worked together in groups to decide on the essential elements of an investigative project and then individually critiqued one of their peers project proposal assignments	Critiquing experiments	
11	Preparation of gases	Particulate nature of matter	Students collected gases using simple apparatus and then examined the properties of oxygen, hydrogen and carbon dioxide.	Lab skills	

- Misconceptions have been identified over the course of the module and from literature (Kind, 2004)

5.5 Design of Assessment Strategy

Traditionally the chemistry module was assessed based on completed laboratory notebooks and weekly written laboratory tests. The lab tests were used to determine students' knowledge of chemical concepts and the completed laboratory notebooks tested the students' knowledge of chemical concepts and included a section on how they would use the activities in teaching. A previous study carried out by the researcher involving a comparison of results from the notebooks and lab tests of a similar cohort of students (Hinch, et al., 2013). This study determined that laboratory notebooks were not an effective tool to assess learning within a laboratory context. However, they are useful for students to record details of their activities for future use. This study is described briefly in Section 5.5.1.

In light of this and the new framework of the module, an alternative assessment strategy was developed, and shall be discussed under Section 5.5.2.

5.5.1 Laboratory Notebooks Study

The grades obtained from their lab notebooks and their lab tests over the course of a lab module run for 6 weeks in semester 1 and 6 weeks in semester 2 of a similar cohort of students (N = 33) was analysed. Most of the marks for the notebook were assigned for discussion of chemical concepts and discussion of where the lab activities could be used in their future teaching. A smaller portion of the marks were for the procedure and overall report layout.

When the students' average grade in their lab notebook was compared to their average grade in their lab tests over the year, it was found that there was a significant difference between them ($p = 0.023$). The relationships between these grades are shown in Figure 5.3 and indicate that generally the students were achieving higher marks in lab tests than in notebooks. The grades are not shown numerically, but are represented as a gradation from very poor to excellent.

The notebook grade was then separated out so that the grades assigned for chemical concepts could be plotted against average lab test grade (Figure 5.4).

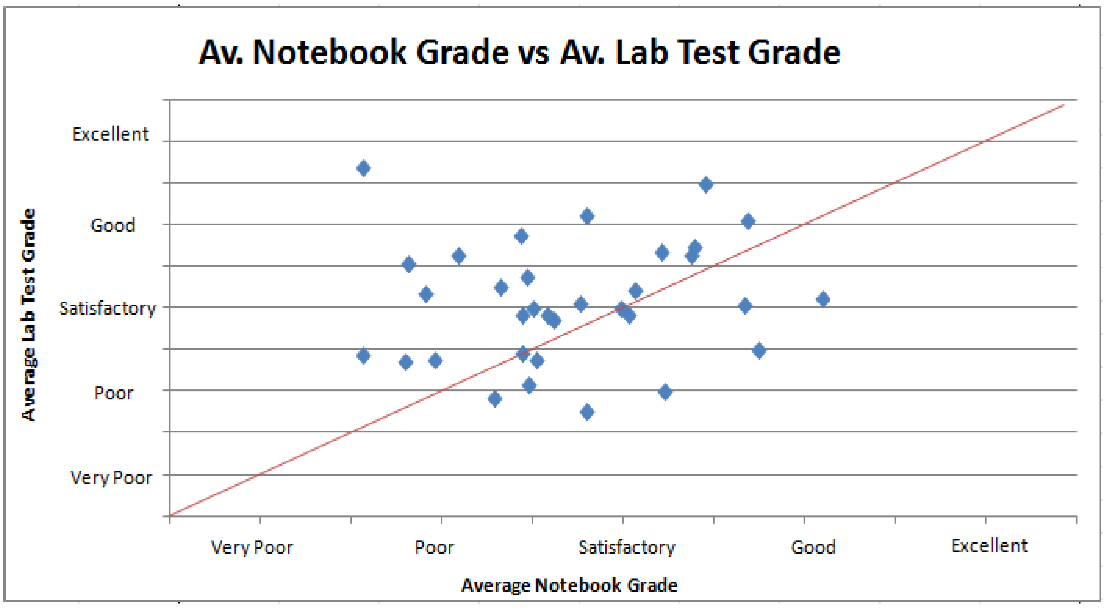


Figure 5.3: Average lab test vs average notebook grade

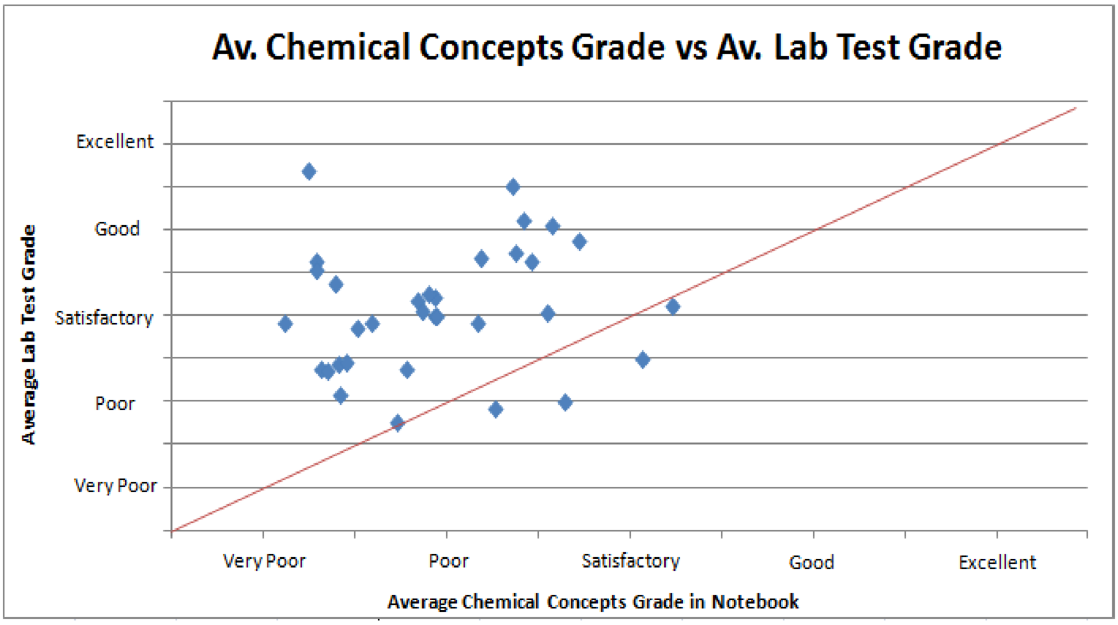


Figure 5.4: Average chemical concepts grade vs average lab test grade

The data shown in Figure 5.4 was extended to 3D to show the number of students included in each segment. The graphs (Figures 5.5 & 5.6), representing the results from semester 1 and 2 respectively, clearly demonstrate the disparities between these grades.

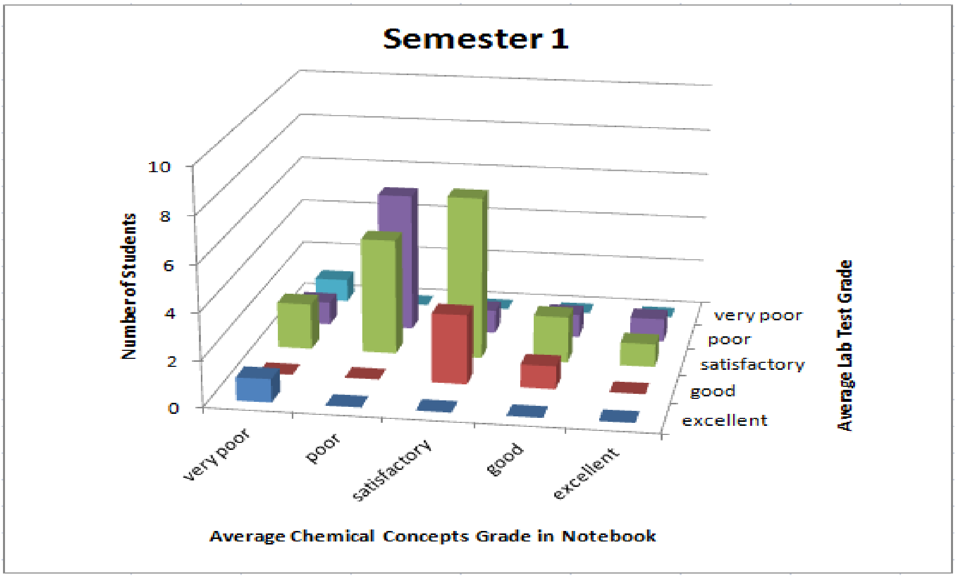


Figure 5.5: 3D representation of the number of students obtaining different grades in their chemical concepts in their notebooks and lab tests in semester 1

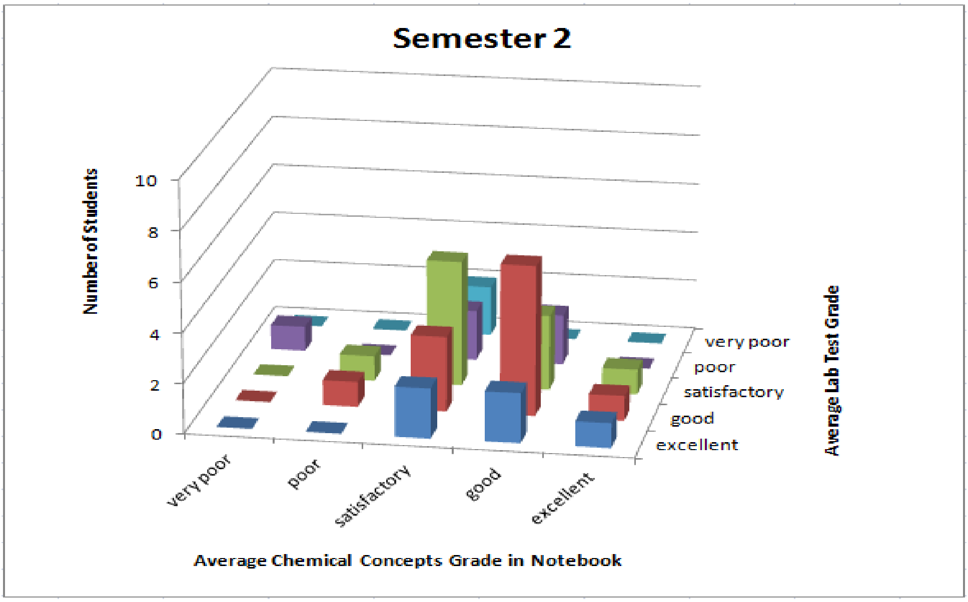


Figure 5.6: 3D representation of the number of students obtaining different grades in their chemical concepts in their notebooks and lab tests in semester 2

The grades awarded for understanding of chemical concepts as shown in the notebook is generally lower than that shown in the lab tests. From tutor-student discussions during labs, grades in lab tests were considered a better reflection of student understanding. The grades improved from 1st to 2nd semester (Figure 5.5 and Figure 5.6), but in semester 2, there was still a proportion achieving a satisfactory grade in chemical concepts in notebook and poor/very poor grades on lab tests (Figure 5.6).

As a result of these findings, the use of lab notebooks is not considered to be very appropriate for assessing understanding of chemical concepts covered in the lab. The assessment is not reliable as the students display different levels of understanding in lab tests on the same concepts. The validity of the notebooks is questionable. Different assessment methods should be utilised to ensure that the participants have the opportunity to demonstrate the skills and content knowledge they have developed over the course of the module (Lovatt, 2009). While notebooks are useful for students themselves as a record of their activities, it is not suitable for grading of conceptual knowledge.

Therefore a variety of assessments have been included in the module. These assessments provided information on the students' content knowledge and on the development of particular inquiry skills.

5.5.2 New Assessment Strategy

A number of different assessment formats have been designed for the module which gave emphasis to the framework skills and competencies outlined earlier. The breakdown in allocation is as follows, and the rationale for each aspect is discussed in the following sections:

- Post-lab assignments and lab tests 40%
- Project proposal and critique 30%
- Notebook 15%
- Conceptual assignment 10%
- Engagement 5%

5.5.2.1 Post- Lab assignments and Lab Tests

Following each lab, the participants completed a post lab assignment and submitted it to an online learning platform. Following each lab session, it was important that students should be asked to reflect on the activities carried out in the lab, the results obtained and the approach taken in the lab (Bennett & O'Neale, 1998). Post lab tasks are invaluable if they are designed to match the aims of the laboratory (Reid & Shah, 2007). Hence, post labs were assigned each week that focussed on three aspects:

- Content knowledge and skills encountered in the lab;
- Questions relating to particular misconceptions either identified through lab discussions or literature;
- How to teach the particular topic, addressing any misconceptions if relevant.

Timely and constructive feedback is an essential part of learning (Black & Wiliam, 1998) and hence it was designed that students would be given feedback on their post lab assignments in advance of the next lab session and in advance of the weekly lab test. The feedback would be given in the form of additional guiding questions as well as direction towards answers.

The majority of content knowledge was assessed through weekly pen and paper tests carried out in lab and on an individual basis. The combination of post lab – feedback – lab test was considered appropriate to focus the student on the essential learning of the weekly activity and to also provide evidence of student learning throughout.

5.5.2.2 Project Proposal and Critique

The participants were asked to design a practical project proposal for a science forum, such as Young Scientist, for a junior cycle group. They did not actually have to carry out the proposal, but they needed to plan a suitable investigation that could be carried out in a school setting. This assessment was very important for the development of the participants' inquiry skills, particularly their ability to plan an investigation.

An important skill for an inquiry teacher is to be able to guide students in developing their own questions and investigations. Therefore it was important that the PSTs were given an opportunity to do this themselves as "learners".

While there was not time within the module for them to conduct their own large investigation, the exercise of them planning such an investigation was important. The guidelines provided to the students were:

"You will develop a practical project proposal for a science forum, such as Young Scientist, for a junior cycle group. You will not actually have to carry out your proposal. Your proposal should include:

- *The project question/ research question;*
- *What is known about the problem/ background information;*
- *How are you going to answer this question (methodology, including the control of variables);*
- *What experiments you will conduct;*
- *What results are expected and their limitations/ accuracy."*

This exercise was considered very useful, to show how their inquiry skills have been developed and hence was given a large proportion of the module marks.

An essential follow up of this was to develop their ability to critique the proposals. While the project proposal was individual, groups of 4 students then critiqued a number of proposals. Following submission of the individual project proposals, the students then in groups of 4, developed criteria for the assessment of the proposals and provided a critique of their peers. This involved the development and display of the students critiquing experiments skill. Within the critique, they could identify lack of clarity in the proposals, the suitability for classroom environments, the suitability of the project question, etc. The critique would give the students an opportunity to then reassess their own proposals based on their own experience of critiquing as well as the critique provided by their colleagues. The students were then allowed to resubmit their proposals following changes made as a result of the critiquing session.

5.5.2.3 Laboratory Notebook

The students' laboratory notebook will be assessed, but it will not be the sole form of assessment. The main reason for using the notebook was to act as an aid-memoire for the student. Therefore marks were allocated to encourage students to take appropriate notes, to engage with the laboratory activities, the content covered, visualisations, and to consider how they would carry these activities out in future. The participants were required to maintain their laboratory notebooks each week.

Here they would include everything that was required to complete the experiment again, and they would identify where the completed activities linked to the learning outcomes of the new Junior Certificate Science Curriculum. This was to demonstrate that inquiry activities are suitable for achieving the aims of the curriculum.

The guidelines that students were given for their laboratory notebook are:

"*For these labs, you will maintain a laboratory notebook. Your notebook should have all the information necessary for you to repeat this experiment later. It should also address the chemical concepts covered, molecular level drawings should be included as much as possible and also how the activity is related to the new Junior Science Curriculum. Headings should include:*

- *Date:*
- *Experiment title: including what you are trying to do within this activity*
- *Resources / materials required – include how solutions should be prepared, safety information*
- *Procedure adopted*
- *Results obtained and interpretation of results*
- *Detailed molecular level drawings required*
- *How can I use this activity to address one/ more learning outcomes given in the Junior Cert curriculum?* "

5.5.2.4 Conceptual Assignment

The misconceptions assignment which was a part of the assessment strategy for this laboratory module has been described in Section 5.4.5. This assignment was designed to engage the participants both in the identification of misconceptions in chemistry that they may have, but also to have them reflect on how they would teach this area so that their own future students would not develop these issues. This assignment was designed so that the students could engage in a teaching aspect without actually having to teach it. Also this would be a useful assignment to determine the PSTs' approach to teaching. As part of this assignment the PST describe how they will teach a topic so that students don't develop misconceptions and they are likely to describe what they consider to be good practice and how they may eventually plan on teaching.

5.5.2.5 Engagement

To encourage full participation by the students in the lab activities, a small allocation of marks was allocated to engagement. Engagement included regular on-time attendance, involvement in lab and group discussions as well as respectful interactions with others in the lab.

5.5.2.6 Importance of Feedback

Timely and constructive feedback is an essential part of learning (Black & Wiliam, 1998). Students need to continuously be given feedback as to their progress in learning situations therefore feedback was considered to be very important within this module. The assessment was designed in such a way that timely feedback could be given each week on post lab assignments and in-class feedback was given on tests.

Following the submission of their project proposals, the participants carried out peer assessment on one of their peer's project proposal assignments. The PST developed assessment criteria in groups of four and used this to give feedback to their peers. Grades were not given to the PST until towards the end of the module. This was done so that the participants would engage with the feedback and would not focus solely on their grades achieved (Black & Wiliam, 1998).

Feedback was provided to the participants on each of their submitted post labs via an online learning platform. Immediately following each test that the participants took during their labs, the academic instructor went through each item and discussed some issues that were found within the tests. Individual feedback was provided on their laboratory notebooks during the module to ensure that participants were completing them properly and including all required aspects. Feedback was provided on their project proposal titles via the online learning platform. In this way, good practice was implemented in terms of assessment practices, such as feedback (Nicol & Macfarlane-Dick, 2006), peer assessment (van Zundert, et al., 2010) and no grades (Black & Wiliam, 1998).

5.6 Conclusion

The analysis of the data in Phases 1 and 2 have allowed for the development of a profile of the PSTs in relation to teaching through inquiry and assessing inquiry practices. This has informed the development of laboratory based module for PSTs as outlined in this Chapter. The main conclusions from this Chapter are discussed under the headings of overall design, framework, and assessment strategy.

5.6.1 Overall Design

Analysis of the PSTs in Phase 1 and Phase 2 provided information about PSTs across Europe and the effect of specific inquiry programmes on the participants. This chapter focussed on the design of a module for PSTs, developed using the results of Phases 1 and 2. The aim of this module was to provide opportunities for the students to experience inquiry first-hand, learn content and develop skills through inquiry, and experience formative assessment.

A case study methodology was chose for this phase of the research as it fits the needs of this study, which was to describe the development, teaching and learning in a chemistry lab module aimed at pre-service science teachers. This constitutes a “banded context” which can be studied using a case study approach.

The design of the module took into consideration the scientific background of the PST cohort and their minimal level of teaching experience (micro-teaching only).

This module was chosen as it was a chemistry module which is a subject that the chosen cohort is unfamiliar with. This was important as the PST were to experience inquiry first-hand in the role of the student, and this would be achieved best with an area that is new to them.

5.6.2 Framework

A framework for the 33 hours of an undergraduate chemistry laboratory to include 6 key aspects was developed.

The use of visualisations or representations of phenomena in chemistry was chosen as a focus for this lab primarily because the cohort participating had a limited understanding of chemistry prior to the implementation of the module.

A key aim was to enhance PSTs' views of science and how school science relates to science research and nature of science.

Traditionally laboratory modules involve students carrying out experiments where the procedure is provided and the results are known in advance. However, the approach adopted here advocated that inquiry laboratory activities have the potential to support collaborative social relationships in addition to cognitive development and improve attitudes towards science.

TEPs where teachers are immersed in authentic inquiry will more likely enhance teacher knowledge, prepare teachers to implement inquiry instruction, and lead to enhanced student understanding. To provide the participants with as full and comprehensive a view of inquiry learning as possible and immerse them as much as possible, different lab sessions focussed on the utilisation and development of different inquiry skills.

Due to this particular cohort's minimal background in chemistry, a particular focus on content was deemed necessary. The chemistry content covered within the module should link to the learning outcomes of the new Junior Certificate Science course as this is what these PSTs will teach. Misconceptions and alternative conceptions were addressed as they arose.

5.6.3 Assessment Strategy

A new assessment strategy was developed for this module and incorporated five aspects – notebooks, lab-tests, project proposal and critique and student engagement. The assessment strategy was designed to engage the student with particular activities but also to encourage their full participation with all aspects of the module. Allocation of assessment marks for particular skills also highlighted to the students the importance of such skills.

Traditionally the chemistry module was assessed based on completed laboratory notebooks - however the researcher determined that laboratory notebooks were not an effective tool to assess learning within this laboratory context. Non-graded and written individual feedback was to be provided regularly on notebooks, post lab-tests and project proposal and critique.

A range of assessments were designed to reward the student for development of skills as well as knowledge.

Chapter 6 now details the results of the evaluation of the module.

Chapter 6 – Evaluation of Undergraduate PST Module

Chapter 5 described the design of a chemistry module for PSTs, developed using the results of Phases 1 and 2 of this research. The aim of this module was to provide opportunities for the students to experience inquiry first-hand, learn content and develop skills through inquiry, and experience formative assessment. The framework for the module was given previously in Table 5.1. This chapter describes the evaluation of this module. Section 6.1 discusses the evaluation methodology with results and discussion given in Section 6.2.

6.1 Methodology of Evaluation

This module has been evaluated based on the participants' views towards science teaching, the content knowledge gained, the inquiry skills shown, and the teaching approaches demonstrated.

The module has been evaluated using different evaluation tools and student materials (summarised in Table 6.1). The particular analysis method used depended on the type of data collected and therefore the analysis method is discussed together with the evaluation tool used in the following sections. Much of the data was also analysed by multi-dimensional scaling (MDS) analysis using an ALSCAL algorithm to examine similarity/dissimilarity between data. This has previously been described in Section 2.7. Ward's method was used to determine the number of clusters in the dataset, followed by a k-means algorithm to determine which cluster a particular data point belonged to. MDS was used to compare the dissimilarity between different groups by using the average response for each question as the input for MDS.

In addition to the various evaluation forms that are used in this module, the researcher kept a journal throughout. The researcher kept notes on the laboratory sessions as they were occurring, noting information regarding how the lab progressed, whether the students engaged with the inquiry skills that were an important aspect of that particular lab session, aspects that students struggled with and identified misconceptions.

Table 6.1: Aspects evaluated and methods used

Key Aspects Evaluated	Evaluation Tool	Timing	Section
Views towards science teaching	Pre & Post questionnaires (Appendix A.6)	Pre questionnaire given before first lab session Post questionnaire given after last lab session	6.1.1
Content knowledge	Lab tests – T1 – T3, T5 – T10	Beginning of each lab from session 2	6.1.2
Planning Investigations	Lab tests and Post lab assignments - PL2, 4, 7, 8; T2, 4, 6, 7, 8, 10; Project	Lab tests - Beginning of each lab from session 2 Post lab – Made available on Tuesday, assignment submitted by Thursday and feedback provided by Friday in time for next lab on Monday.	6.1.3.1
Critiquing Experiments	Project proposal critique	Assigned at the beginning of the module. Following submission, critiqued in lab by students in next lab. Students given week to submit final version.	6.1.3.2
Teaching Approach	Post lab assignments PL 2, 3, 5, 6 , 7 and Conceptual Assignment	Post lab – Made available on Tuesday, assignment submitted by Thursday and feedback provided by Friday in time for next lab on Monday.	6.1.4
Visualisations	Laboratory Notebook	During each lab sessions and/ or when writing up their notebook	6.1.5

The areas that students struggled with were noted by the researcher so that further activities and questions could be designed to help address these issues for students. Extracts from the journal are included within the discussion of results in Section 6.2.

The evaluation tools and methods of analysis used, as outlined in Table 6.1, are now discussed in detail in Sections 6.1.1 – 6.1.5.

6.1.1 Views towards Science Teaching

One questionnaire (given in Appendix: A6) was developed which was completed by the module participants before and after the module. It consisted of thirty five items and all items within the questionnaire could be matched pre and post the module to determine any changes across all of the areas discussed.

Descriptive statistics were conducted on the obtained data. The data in this questionnaire is non-parametric which determines many of the statistical tests that are conducted in this work. As outlined previously (Section 2.7), the Kruskal – Wallis test is the non-parametric alternative to the One-Way ANOVA test. It is used here to evaluate differences between three or more conditions or populations using data from an independent-measures design. Where the One-Way ANOVA test requires the calculation of means and variances of data, this test simply requires that the individuals in the data can be rank ordered for the variable that is to be measured. The Wilcoxon test is the non-parametric alternative to the dependent t-test. The difference between the measurements for each individual is taken as the score for that participant. Much like the Kruskal – Wallis test, the Wilcoxon Signed-Ranks test requires the ranking of data. Multi-dimensional Scaling (MDS) analysis using an ALSCAL algorithm was used to examine similarity/dissimilarity between data.

6.1.2 Content

One of the aims of the module was to develop the PSTs' content knowledge. The participants' content knowledge was determined from responses on their laboratory tests (noted as T1 – T3, T5 – T10, signifying the sequence of the lab tests). The tests contained questions relating to content knowledge, misconceptions and inquiry skills.

Only the questions in T1 – T10 relating to content knowledge were analysed in this section. Although content knowledge questions were included within the post lab assignments (PL1-9) these were not included in this analysis as they were carried out by the participants at home so information may have been written with the aid of textbooks, their peers or the internet. So, to determine whether students have actually learned chemistry, their test results are used. After the content knowledge questions were selected (see Table 6.2 for samples of questions), sample answers were generated for each item and marks were assigned based on whether the students demonstrated sufficient knowledge. The assigned values were independently checked to confirm that the marks were appropriate. The assigned marks within each test were then summed and expressed as a percentage of the total marks available for content knowledge available. The collected results for all students for each test were then normalised. Table 6.3 shows the proportion of marks available for content knowledge across each of the tests.

Table 6.2: Sample of questions from tests

Item	Test
Which of these are reactions? How do you know? **a) Polar ice caps melting** **b) Rusting** **c) Photosynthesis (how plants make food)** **d) Mixing oil and water**	Test 3, question 4
Having followed the procedure to synthesis aspirin, how would you test if your product is indeed aspirin and not your original starting material?	Test 9, question 2
Write the chemical equation for the following reactions, using molecular formulae. **a) Lithium fluoride and sodium hydroxide** **b) Potassium chloride and lead (II) nitrate** **c) Sodium phosphate and copper sulphate**	Test 9, question 5

Table 6.3: Proportion of marks available for content knowledge on lab tests

Test	1	2	3	4	5	6	7	8	9	10
Content %	75	20	100	0	80	57	64	33	88	47

6.1.3 Inquiry Skills

Development of the PSTs' inquiry skills was determined from their in-class tests, post labs, project proposal, and their project proposal critique which was carried out in-lab. Two particular skills were focussed on and these shall be discussed separately. These are the skills of planning investigations and critiquing experiments.

6.1.3.1 Planning Investigations

Over the course of the module, the participants demonstrated their skill of planning investigations through their post labs, lab tests and project proposal. The different questions within these assignments required the participants to demonstrate various aspects of the skill of planning investigations. Some assignments included multiple questions for planning investigations. The skill was broken down by the researcher into different aspects which were required for certain questions over the course of the module. The aspects of the skills were assessed multiple times throughout the course of the module as skill development takes time. These aspects are outlined in Table 6.4 matched with the assignments they were demonstrated in. Examples of particular planning investigation items and the aspect of the skill it covers are shown in Table 6.5 and the aspects are indicated in terms of "A, B, C, D, E or F" as given in Table 6.4. Samples of student responses to items where the aspects of the skill were or were not demonstrated as required are shown in Table 6.6. This highlights how the responses were assigned marks.

The participants' achievements on each of these aspects of the skill were determined across all assessments. To do this, the researcher used the skill aspects in Table 6.4 to check whether or not required aspects were included in each particular question. In this way, changes in the skill level of individual participants could be identified and monitored. In each assignment, it was noted on an individual basis whether they had included that particular aspect of the skill (on the basis of 0 or 1). These marks were combined for each individual to obtain a combined mark for planning investigations.

Table 6.4: Evaluation of Skill of Planning Investigations

Aspect of skill	Assignment*
(A) Method is appropriate for achieving the goal. Not fair testing, but the properties of substances are taken into account.	PL2, 4, 7, 8; T2, 4, 6, 7, 8, 10; Project
(B) Mentions all materials required, not just technique.	PL2, 4, 7, 8; T2, 4, 6, 7, 8, 10; Project
(C) Individual steps of the experiment are described clearly. Steps are not combined into one statement.	PL2, 4, 7, 8; T2, 4, 6, 7, 8, 10; Project
(D) Fair testing, what is being changed, what is being kept constant, etc.	T4, 6, 8, 10; Project
(E) End point of experiment chosen with reason	T4, 8, 10
(F) Measurements included where necessary – e.g., measuring time	T4; PL4

*PL – post lab, T – test

Table 6.5: Planning Investigations items and the aspects of skill

Item in Post Lab or Test	A	B	C	D	E	F
You have been provided with a sample of "sand" from the seashore. It contains salt, small stones and fine sand. Suggest a way of getting a pure sample of each component. **– PL2, question 4**	X	X	X			
When vitamin C tablets are added to water, bubbles are observed suggesting a reaction is taking place. Effervescent vitamin C tablets contain ascorbic acid (vitamin C), sodium carbonate (Na_2CO_3) and citric acid ($C_6H_8O_7$). Describe a way to measure the rate of this reaction (include what variable(s) you are keeping constant and what you are changing/measuring. **– PL4, question 2a**	X	X	X	X	X	X
Plan an investigation to determine if tomatoes are more acidic than kiwis. In your investigation, suggest how you would neutralise the acid and hence determine the amount of acid present. You can assume that all acid present is citric acid. **- PL7, question 2**	X	X	X			
You have a mixture of petrol and diesel. What property and method would you suggest to separate these? **-T8, question 3**	X					

Table 6.6: Samples of students' Planning Investigations responses

Item	You have been provided with a sample of "sand" from the seashore. It contains salt, small stones and fine sand. Suggest a way of getting a pure sample of each component.- **PL2, question 4**	**Correct answers should have A, B and C.**
Student response	*"Firstly I would put the sample of sand through a colander this would separate the stones from the sand and salt, leaving a pure sample of stones. I would then add the salt and sand to a beaker of water. The salt will dissolve in the water. Then I would get a filter and filter paper and put the beaker of water and sand through the filter. The sand will be filtered by the paper. Then in order to get a pure sample of salt I will heat the water with a Bunsen burner. The water will evaporate off leaving the salt in the bottom of the beaker."*	Aspects A, B and C are all included and a mark of 1 was assigned for each aspect.
Student response	*"The sand will separate if you boil it, you could siv it through a particular gause that will hold the small stones but let the fine sand through"*	Aspects A, B and C were not appropriately dealt with and zero was assigned for each aspect.

To represent changes in the participants' planning investigations skill, the assignments have been split into two groups. The first group was all the information on their planning investigations skill prior to their completion of the "separation challenge" lab. That lab featured the skill of planning investigations heavily, so the data was split to determine their position before and after this lab. Evidence was obtained from post lab (PL) 2, 4 and 7, and test (T) 2, 4, 6 and 7. Only participants who provided a complete set of these 7 assessments have been used. For the second group, evidence was obtained from PL 8, T8 and T10 and their project proposal. Only participants who provided a complete set of these 4 assessments have been used.

6.1.3.2 Critiquing Experiments

The participants were asked to design a practical project proposal for a science forum, such as Young Scientist, for a junior cycle group.

Following submission of the individual project proposals, we discussed in lab the grading schemes used for Scifest (2016) and the BT Young Scientist award (2016). The students then, in groups of 4, developed criteria for the assessment of the proposals. They were not asked to reproduce any criteria or rules suggested previously, but to make their own. After developing their own criteria they then provided a critique on a proposal belonging to one of their peers. Each student participating critiqued one proposal each.

For the analysis of this section, the researcher first read all of the criteria provided by the students. On the second reading, the researcher began to suggest themes / headings for the common aspects that were included. On the third reading, the researcher grouped the criteria that the participants suggested under these headings. This step was repeated to determine any discrepancies that may have arisen between the classifying of the data. These groupings were then used as a classification tool to analyse how the participants carried out their critique. The criteria generated by the students and the frequency of these will be discussed in results Section 6.2.3.2.

6.1.4 Teaching Approach

As it is difficult to determine the approach that participants will take when they begin teaching, an attempt has been made to determine the approach they would use in their teaching of particular topics. The participants were given scenarios in certain post lab assignments where students had differing ideas on a particular aspect of chemistry, and asked to describe how they would teach this topic so that their students would not develop this misconception. They also completed a conceptual assignment as outlined in Section 5.4.5. How the participants suggested they would teach a topic provides information on their approach to teaching. The responses the PSTs gave were analysed and the approach adopted was categorised on a scale from 1 to 6, ranging from chalk and talk type teaching to open inquiry, see below. Levels 3 to 6 are as presented by Banchi & Bell' (2008).

1. Chalk and talk – Teacher explains while the student listens. The teacher is the source of knowledge and it is transmitted to the students.
2. Demonstration/ activity – Teacher demonstrates something or asks students to carry out a basic activity to explain something.
3. Confirmation inquiry – Students confirm a principle through an activity when the results are known in advance.
4. Structured inquiry – Students investigate a teacher-presented question using a pre-designed or selected procedure where they develop their own conclusion.
5. Guided inquiry – Students investigate a teacher-presented question using student designed/ selected procedures.
6. Open inquiry – Students investigate questions that are student formulated through student designed/ selected procedures.

An experiment or activity was classified as structured inquiry if the question and procedure was provided but the students did not know the outcome in advance, or the students were drawing conclusions for themselves. A participants' approach was classified as guided inquiry if the question or task was provided by the teacher but the students had a role in deciding how they would answer the question and draw conclusions. This scale and classifications has been independently validated. Table 6.7

provides examples of each of the levels that were provided by the students in their work.

No example of open inquiry is shown in Table 6.7 as no student depicted open inquiry over the course of the module. In several instances, participants' descriptions included more than one option listed above. For analysis, in each case the highest number was used. Often participants would suggest a chalk and talk aspect before a confirmation inquiry activity. In this case, the number 3 was selected. This holds true if a participant suggested a chalk and talk session covering key points of a topic before giving a task to complete where the school students did not know what the outcome was or what procedure was suitable. The number 5 would be assigned in that situation as the participants had suggested a guided inquiry activity.

Table 6.7: Examples of excerpts from students' teaching approach

Student Excerpts	**Assigned Level**
"By explaining that atoms will try and achieve a full outer shell of electrons, it would help students to understand why ions form and their charges change."	1
"Use two different colours of modelling clay e.g. blue and yellow. Tell the students that the blue is hydrogen and the yellow is oxygen. Explain to the students…" **Or** "Mix iron fillings and sulphur powder in any proportion. Hold a magnet over the mixture to separate iron back out of the mixture. This shows that a mixture is two or more substances mixed but the substances retain its identity."	2
"The students could carry out this experiment in a zip lock airtight bag so that they could see when the reaction took place a gas would be released but it would be kept in the airtight bag."	3
"….They can test multiple acids and bases until they come to the conclusion that depending on the amount of H ions, the substance is acidic or basic and if the hydroxide and hydrogen ions are equal then the solution is neutral, it still contains H ions"	4
"Students could be given various apparatus with which they can examine the tablets… students could be asked if they can see any bubbles within the tablet …it will allow students to formulate their own opinions and conclusions as to whether or not the bubbles are inside the tablet.	5

6.1.5 Visualisations

In addition to the development of a deep understanding of chemistry, an emphasis on visualisations was included within this module as it could be used for diagnosing any specific issues that students have in particular areas of chemistry. Students created their own visualisations representing their mental views of concepts during the laboratory sessions, and the instructors used these to identify any misunderstandings they had and to initiate discussions on the topic.

The representations were produced within their laboratory notebooks. Students were asked to include molecular level diagrams wherever appropriate within their notebook write ups. Representations were also produced as tasks during certain laboratory sessions. This module successfully incorporated the use of visualisations into the laboratory module. The representations generated will not be analysed, but they shall be discussed as they were a key aspect of the framework of the module.

6.2 Results and Discussion

Each aspect of the evaluation as outlined in Table 6.1 is now presented. Details on statistical tests can be found in Section 2.7.

6.2.1 Views towards Science Teaching

For ease of discussion, the thirty five items on the questionnaire (Appendix: A6) have been grouped for analysis based on the following aspects:

- Control in the Classroom
    - Allowing students to take ownership
    - Teacher centred control
- Teacher confidence in ability to teach inquiry
    - Teacher confidence in their ability to teach through inquiry
    - Teacher lack of confidence in their ability to teach through inquiry
- Confidence with science and science teaching
- Effectiveness and effort in science teaching
    - Effectiveness of approach in science teaching
    - Teacher effect and teacher effort

Twenty six students completed both the pre and post versions of the questionnaire (35% male, 65% female). These 26 participants provide a matched set for the questionnaires and only data from the matched set is analysed and discussed in the initial profile and the change in responses. Results of the whole cohort are used for comparison with other aspects of the programme.

6.2.1.1 Control in the Classroom

Control in the classroom relates to the participants' comfort both with allowing students to take ownership of the direction of their learning and conversely with their own desire for more teacher-centred control. Questions posed and responses given are shown in Tables 6.8. and 6.9.

From Table 6.8, the pre-module data suggests that about half of the participants are "uncertain" as to being comfortable with allowing students to take ownership of the direction of science investigations, allowing their students to develop their own methods of investigations and developing their own explanations of results.

Following the module, the post data shows significant shift to stronger agreement on all of these statements.

The majority (69.2%) however agreed or strongly agreed that they would be comfortable with students developing their own science investigation research questions and this level did not change significantly after the module. This was an area that the participants found difficult themselves when asked to develop a project proposal so it is interesting that this was something that they wished their students to do.

There is a wider distribution of responses on teacher-centred control (Table 6.9) with agreement that they will feel best when they have complete control of all student activities (35%), when students are carrying out structured lab experiments (46%), and their highest priority is keeping students on task (61.5%). Following the module, there is a significant shift towards disagreeing with the first two statements. Keeping students on task remains a highest priority for about half of the participants.

The data was analysed by MDS and is shown in Figures 6.1 and 6.2. The max point on the MDS graph in Figure 6.1 represents the most positive response to the items relating to comfort with students taking ownership in the classroom. The max point indicated on Figure 6.2 is that of fully believing they would feel best with having complete control and being primarily focussed on keeping students on task. The blue points on the graph represent positions of participants initially, the green points are positions following the module, and the orange represent points where there are two or more points overlapping which are both pre and post-module results. The maximum response can be represented by either yellow or purple. The max point is purple if there are no overlapping responses. The point is yellow if participants are overlapping and responding the same as the max value. The MDS graph allows for visualisation of the general trend of students before and after the module.

It is clear from Figure 6.1 that participants are shifting towards being more comfortable with students having some control over experimental work in the classroom with many participants from after the module indicating complete comfort with students taking ownership. Following the module there are more participants shifting away from this max point in Figure 6.2 than there are moving towards it. It is clear that the participants are more open to students having some ownership and with them having less control in the science classroom. Taken together, these results indicate a move from teacher centred control of dictating student learning to a more student centred approach, allowing the students to be involved in directing their own learning.

The activities and approach taken in the module has therefore been beneficial to the participants to allow them to be more open to student-centred approaches.

Table 6.8: Pre and post results for "Allowing students to take ownership"

Statement		SD	D	U	A	SA	Z	P
3. Given the opportunity, I think that I will be at ease having students take more ownership over what direction we take in our science investigations	Pre	0.0%	0.0%	57.7%	42.3%	0.0%	-2.496	.013
	Post	0.0%	0.0%	30.8%	61.5%	7.7%		
7. I think that I will feel comfortable allowing students to develop their own science investigation research questions	Pre	0.0%	15.4%	15.4%	65.4%	3.8%	Not sig.	
	Post	0.0%	0.0%	19.2%	69.2%	11.5%		
13. I think that I will feel comfortable giving students a problem to focus on and allowing them to come up with their own methods of investigation and analysis	Pre	0.0%	0.0%	42.3%	57.7%	0.0%	-3.127	.002
	Post	0.0%	0.0%	7.7%	76.9%	15.4%		
19. I think that I will be at ease allowing my students to develop their own explanations for their findings	Pre	0.0%	0.0%	42.3%	57.7%	0.0%	-2.673	.008
	Post	0.0%	0.0%	11.5%	80.8%	7.7%		

*(SD ,D, U, A, SA = strongly disagree, disagree, uncertain, agree and strongly agree; See Section 2.7.2 for explanation of Wilcoxon Signed Rank)

Table 6.9: Pre and post results for "Teacher Centred Control"

Statement		SD	D	U	A	SA	Z	P
12. I think that I will feel best when students conduct structured laboratory experiments	Pre	0.0%	0.0%	50.0%	46.2%	3.8%	-2.221	.026
	Post	3.8%	26.9%	19.2%	46.2%	0.0%		
14. I think that I will feel best when I have complete control of all of the student activities in the classroom	Pre	0.0%	19.2%	38.5%	34.6%	7.7%	-2.433	.015
	Post	7.7%	30.8%	42.3%	15.4%	3.8%		
20. Keeping students on task will be my highest priority in the classroom	Pre	0.0%	11.5%	23.1%	61.5%	3.8%	Not sig.	
	Post	0.0%	19.2%	30.8%	46.2%	3.8%		

*(SD ,D, U, A, SA = strongly disagree, disagree, uncertain, agree and strongly agree; See Section 2.7.2 for explanation of Wilcoxon Signed Rank)

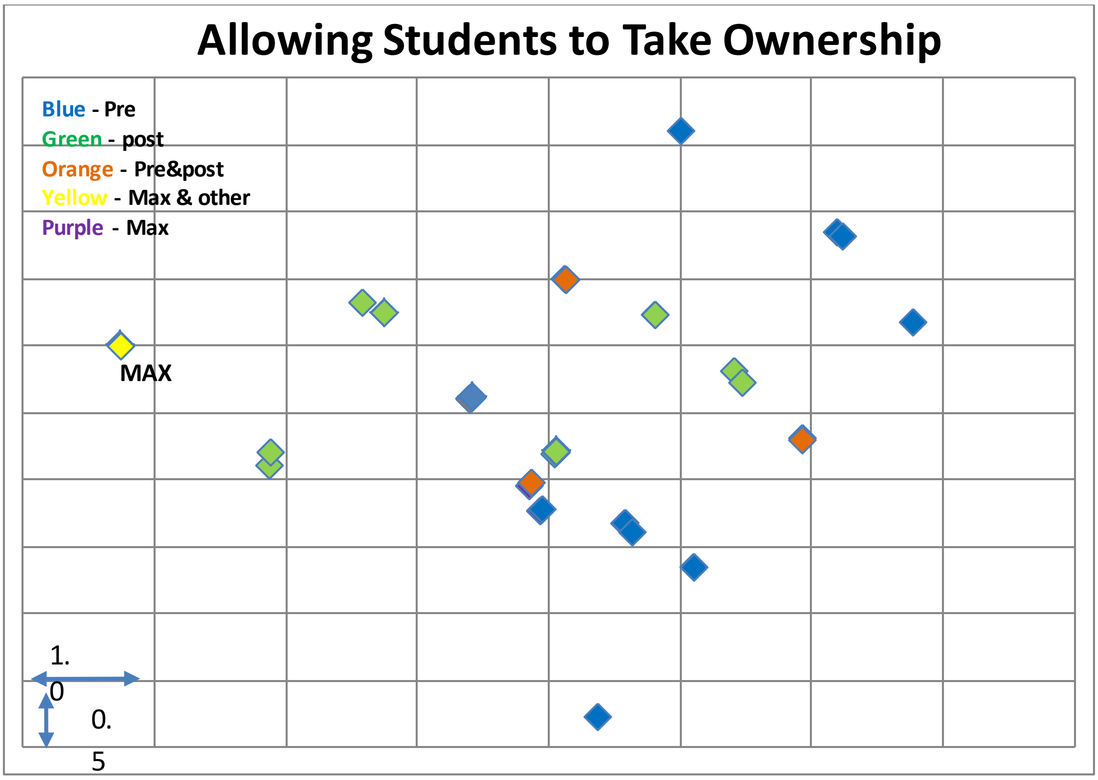


Figure 6.1: Change in Allowing students to take ownership – MDS Analysis

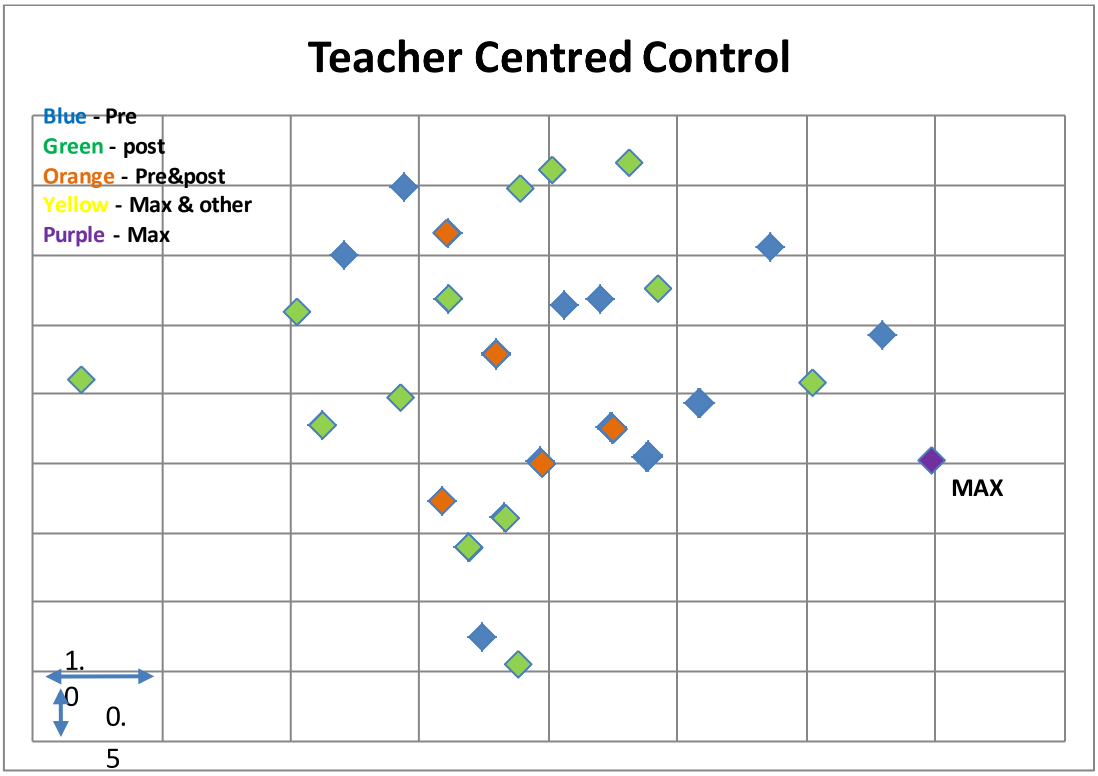


Figure 6.2: Change of Teacher Centred Control – MDS analysis

6.2.1.2 Teacher Confidence in Ability to Teach Through Inquiry

This section discusses the PSTs' confidence in their ability to teach through inquiry. Two sets of statements were given where one was focussed positively (see Table 6.10) and one negatively (see Table 6.11). When asked about their confidence prior to the module the participants were quite positive about their ability to teach their students through inquiry. The only area where the majority feel uncertain relates to their own understanding of scientific research and if they understand it well enough to be effective when supporting their students (Table 6.10). They were most positive about their ability to monitor a science investigation, but they are quite uncertain in their abilities to support students and develop their own questions for investigation and to explain why an investigation did not work. These are areas participants need to be comfortable with to teach through inquiry effectively (Table 6.11).

Following the module the participants changed significantly on one item relating to their confidence, indicating that they now understand the scientific research process well enough to be very effective in supporting student research investigations. This was the item where participants were mainly uncertain in their responses prior to the module.

Two significant changes were determined in the items relating to their lack of confidence teaching in the inquiry classroom further indicating that the participants are now more confident. They are now more confident in their abilities to support students in their development of research questions and investigations.

The data was analysed by MDS and results are shown in Figures 6.3 and 6.4. From Figure 6.3 it is evident that the participants are now more confident in their ability to teach through inquiry as they have made some shifts towards the max point. The max point in this instance represents the most positive response to items 10, 15, 17 and 30 (Table 6.10) which demonstrated a high level of confidence in teaching abilities with inquiry.

Figure 6.4 shows the MDS graph for teachers' lack of confidence in their abilities to teach through inquiry. The max point on the graph relates to responses demonstrating the least confidence in their abilities. Shifts away from the max point indicate an increase in participants' confidence. The graph indicates a shift in participants' responses away from the max point demonstrating that their confidence in their ability to teach through inquiry has increased over the course of the module. Taken together, these results show that the participants are now more confident with teaching inquiry in the classroom.

It is noted of course that these responses are based on the responses to a questionnaire of students who have not yet been on school placement actually teaching. Therefore, it cannot be interpreted that these participants will actually teach through an inquiry approach in practice. However, the results here indicate that they are at least more confident now in their abilities in this respect.

Table 6.10: Pre and post results for "Teacher Confidence with Ability to Teach through Inquiry"

Statement		SD	D	U	A	SA	Z	P
10. I understand the scientific research process well enough to be very effective in supporting student research investigations.	**Pre**	7.7%	15.4%	57.7%	15.4%	0.0%	-3.211	.001
	Post	0.0%	0.0%	42.3%	50.0%	7.7%		
15. When supporting student research investigations, I think that I will welcome student questions	**Pre**	0.0%	0.0%	3.8%	73.1%	23.1%	Not sig.	
	Post	0.0%	0.0%	11.5%	50.0%	38.5%		
17. I think that I will feel very comfortable guiding students, listening to their questions, and supporting their investigations	**Pre**	0.0%	7.7%	26.9%	61.5%	3.8%	Not sig.	
	Post	0.0%	7.7%	11.5%	61.5%	19.2%		
30. I think that I will have the skills to allow students design and conduct their own investigations	**Pre**	0.0%	0.0%	38.5%	61.5%	0.0%	Not sig.	
	Post	0.0%	3.8%	15.4%	73.1%	7.7%		

(SD ,D, U, A, SA = strongly disagree, disagree, uncertain, agree and strongly agree; See Section 2.7.2 for explanation of Wilcoxon Signed Rank)

Table 611: Pre and post results for "Teachers' lack of confidence with ability to teach through inquiry"

Statement		SD	D	U	A	SA	Z	P
6. I think that I will find it difficult to explain to students why their science investigation did not work	**Pre**	0.0%	30.8%	50.0%	19.2%	0.0%	Not sig.	
	Post	7.7%	34.6%	46.2%	11.5%	0.0%		
8. Even if I try hard, I don't think I will be able to support students in developing their own research questions very well	**Pre**	3.8%	50.0%	42.3%	0.0%	0.0%	-2.517	.012
	Post	23.1%	53.8%	23.1%	0.0%	0.0%		
9. I think that I will not be very effective monitoring science investigations	**Pre**	11.5%	57.7%	30.8%	0.0%	0.0%	Not sig.	
	Post	23.1%	53.8%	19.2%	3.8%	0.0%		
16. I don't think that I will know what to do to help students develop their own science research investigations	**Pre**	3.8%	26.9%	57.7%	11.5%	0.0%	-2.646	.008
	Post	3.8%	50.0%	38.5%	7.7%	0.0%		

(SD ,D, U, A, SA = strongly disagree, disagree, uncertain, agree and strongly agree; See Section 2.7.2 for explanation of Wilcoxon Signed Rank)

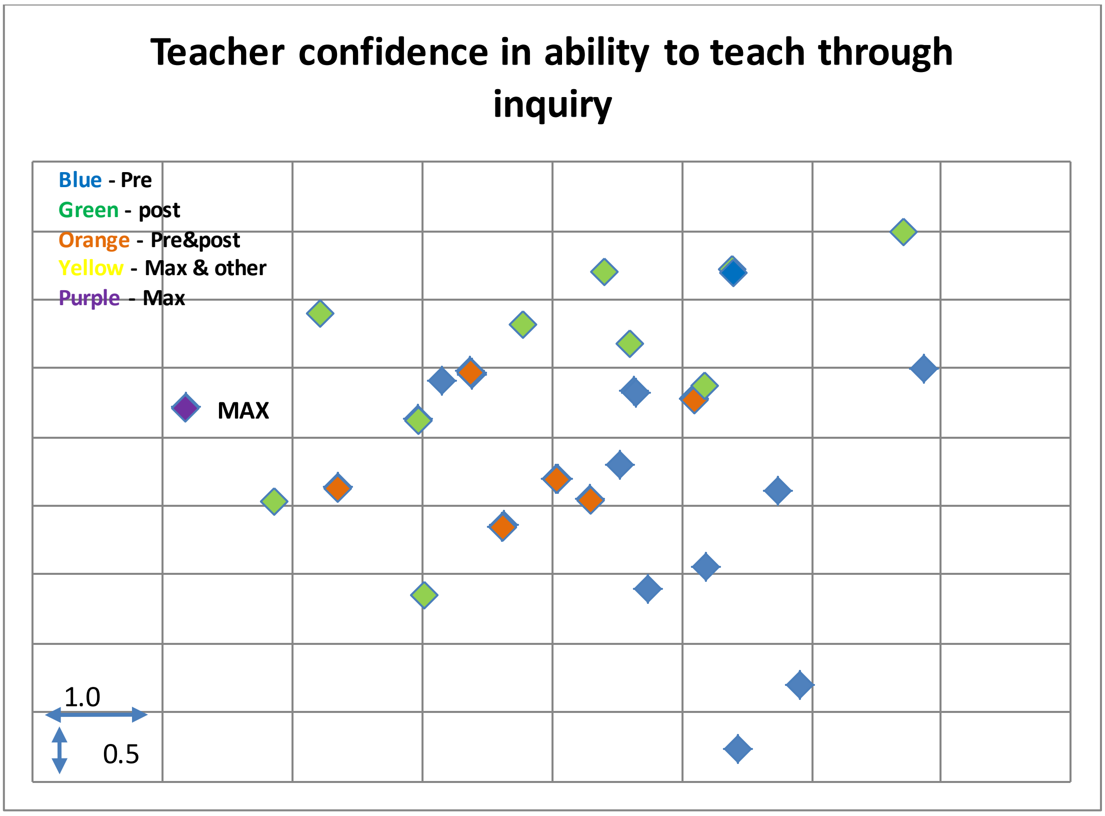


Figure 6.3: Change in Teacher confidence in ability to teach through inquiry - MDS analysis

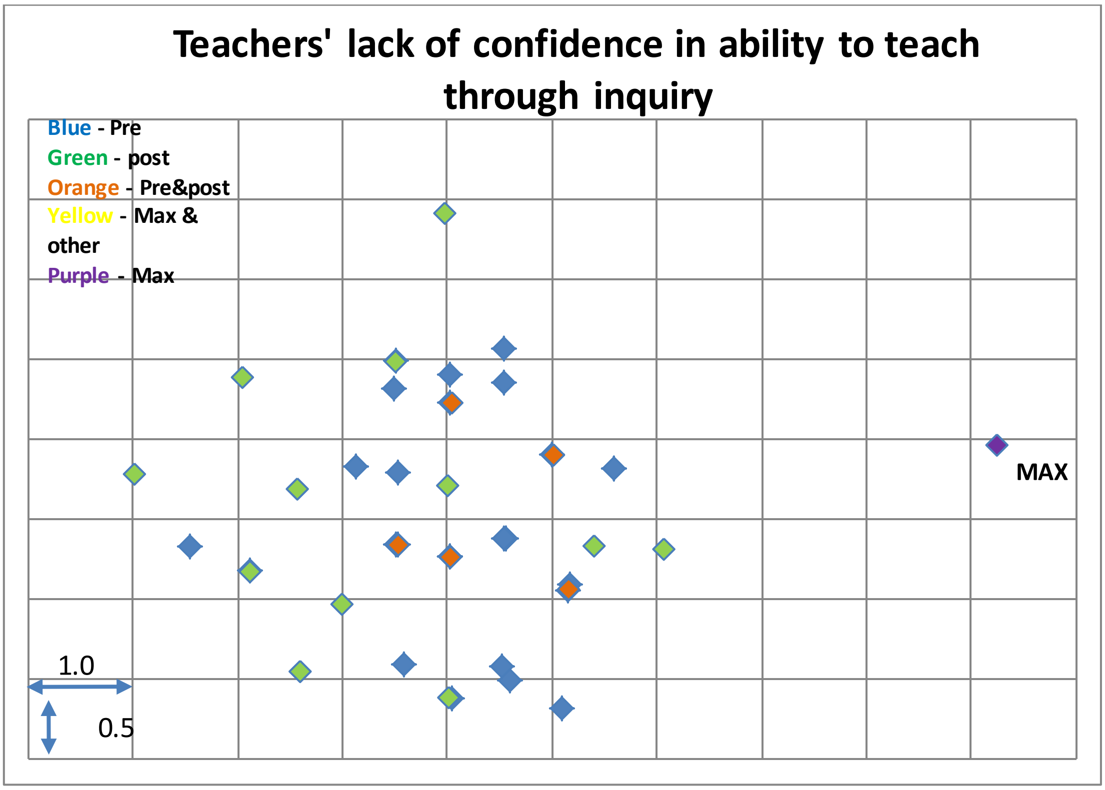


Figure 6.4: Change in Teachers' lack of confidence in ability to teach through inquiry - MDS analysis

6.2.1.3 Confidence with Science and Science Teaching

Five questions on the questionnaire related to the participants confidence in science and the statements and responses pre and post module are show in Table 6.12. Prior to the module there is general agreement that they do well in science courses and are confident in their ability to do science (84%) and understand their science. Most also agree (76%) that they enjoy science but this agreement drops to roughly half when asked if they are confident in their teaching of science.

Following the module, significant changes to higher levels of agreement were evident in their enjoyment of science and their confidence in teaching science.

Results from MDS analysis are shown in Figure 6.5, where the max response indicates the highest level of confidence with science and science teaching. It is clear that following the module there are some shifts towards higher level of confidence, but there were also several PSTs responding significantly close to the max, as indicated by the blue and orange points. This is primarily due to the participants feeling significantly more confident teaching science in their classrooms and enjoying science more than they did prior to the module.

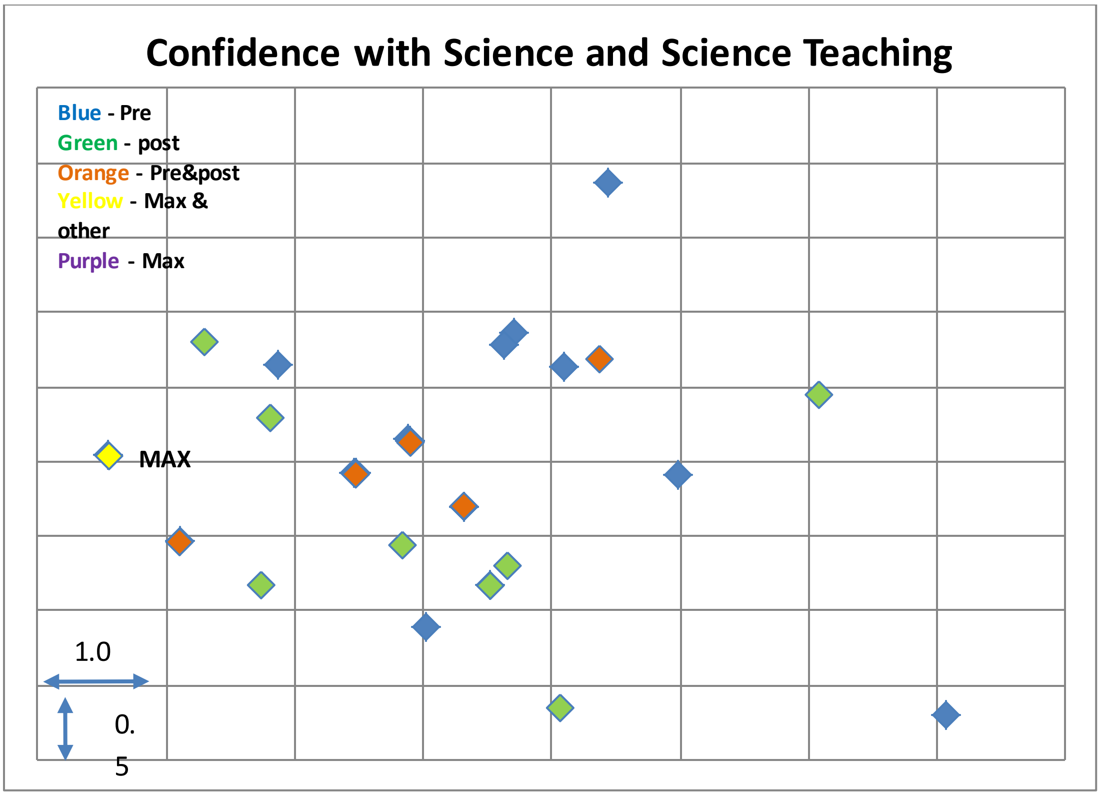


Figure 6.5: Change in Confidence with science and science teaching – MDS analysis

Table 6.12 Pre and post results for "Confidence with Science and Science Teaching"

Statement		SD	D	U	A	SA	Z	P
4. I feel confident to teach science in my classroom	**Pre**	0.0%	3.8%	38.5%	53.8%	3.8%	-2.828	.005
	Post	0.0%	3.8%	7.7%	69.2%	19.2%		
18. I feel confident in my ability to do science	**Pre**	0.0%	3.8%	7.7%	84.6%	3.8%	Not sig.	
	Post	0.0%	0.0%	11.5%	65.4%	23.1%		
21. I enjoy science	**Pre**	0.0%	0.0%	0.0%	76.9%	23.1%	-2.828	.005
	Post	0.0%	0.0%	0.0%	46.2%	53.8%		
24. I usually do well in science courses	**Pre**	0.0%	3.8%	7.7%	84.6%	3.8%	Not sig.	
	Post	0.0%	0.0%	15.4%	69.2%	15.4%		
26. I don't understand science at all	**Pre**	69.2%	26.9%	3.8%	0.0%	0.0%	Not sig.	
	Post	69.2%	26.9%	0.0%	0.0%	0.0%		

(SD ,D, U, A, SA = strongly disagree, disagree, uncertain, agree and strongly agree; See Section 2.7.2 for explanation of Wilcoxon Signed Rank)

6.2.1.4 Effectiveness and Effort in Science Teaching

In this section, questions from the questionnaire have been grouped that link the pedagogical approach with the effectiveness of teaching (results shown in Table 6.13). Half or more of the participants have positive views of the effectiveness of science teaching on students' lack of background in science (Q2, Table 6.13), on students with low motivation (Q31, Table 6.13), and is related to achievement in science (Q23, Table 6.13). There was, however, more uncertainty as to whether a more effective teaching approach is associated with increased student grades (Q22, Table 6.13) or that the student's achievements is related to teacher's effectiveness in teaching science (Q29, Table 6.13). There were no significant changes in the results of the participants over the course of the module relating to the effectiveness of the approach. This indicates that over the course of the module, participants' attitude towards the impact of an effective approach in science teaching has not changed.

Questions have been grouped relating to the impact of a teacher's effort on their students (results shown in Table 6.14). Overall the participants are positive about the impact of the effect of a teacher and a teacher's effort on students, but there are some areas where they are uncertain. Over the course of the module the pre-service teachers changed significantly in their ideas on one statement. Following the module they are significantly more likely to agree that teachers with good science teaching abilities can help some students learn science.

As these are general questions relating to a "science teacher" and not necessarily themselves the results are interesting in that little or no change is observed, indicating that these views are strongly held by the students.

Interestingly, the participants are uncertain about whether teachers are responsible for the overall achievement of their students (Q28, Q29, Table 6.14). However, when specifically referring to students doing better than expected, many of the participants see teachers as being responsible (Q1, Q32, Table 6.14), yet 50% do not believe that low achievement in science can be blamed on teachers (Q25, Table 6.14).

The results in Table 6.14 were analysed by MDS and are shown in Figures 6.6 and 6.7. The max point in Figure 6.6 relates to complete agreement that the effectiveness of a teachers' approach in science teaching impacts their students. There were no significant changes in the results of the participants over the course of the module relating to the effectiveness of the approach. This is clear in Figure 6.6 where there is a homogenous mixture of pre- and post- participants and a change cannot be seen.

The max point in Figure 6.7 indicates complete agreement that teacher effort and the effect of teachers has a positive impact on children's science learning. It is evident that there is a shift in participants' responses towards a greater agreement on the impact of teacher effort. However, there were already several participants responding similarly positively prior to the module. Hence, the module did not appear to have a great impact on the pre-service teachers' ideas about teacher effect and teacher effort, or the effectiveness of a science teaching approach on students, meaning that their views are quite strongly held.

Table 6.13: Pre and Post results for "Effectiveness of Approach in Science Teaching" –

Statement		SD	D	U	A	SA	Z	P
2. The inadequacy of a student's science background can be overcome by good teaching	**Pre**	0.0%	0.0%	3.8%	61.5%	34.6%	Not sig.	
	Post	0.0%	0.0%	7.7%	57.7%	34.6%		
22. When the science grades of students improve, it is most often due to their teacher having found a more effective teaching approach	**Pre**	0.0%	3.8%	46.2%	42.3%	7.7%	Not sig.	
	Post	0.0%	7.7%	26.9%	53.8%	11.5%		
23. If students are underachieving in science, it is most likely due to ineffective science teaching	**Pre**	0.0%	26.9%	23.1%	50.0%	0.0%	Not sig.	
	Post	7.7%	15.4%	46.2%	26.9%	3.8%		
29. Students' achievement in science is directly related to their teacher's effectiveness in science teaching	**Pre**	0.0%	26.9%	38.5%	30.8%	3.8%	Not sig.	
	Post	0.0%	15.4%	38.5%	42.3%	3.8%		
31. Effectiveness in science teaching has little influence on the achievement of students with low motivation	**Pre**	7.7%	57.7%	23.1%	11.5%	0.0%	Not sig.	
	Post	7.7%	50.0%	30.8%	11.5%	0.0%		

(SD ,D, U, A, SA = strongly disagree, disagree, uncertain, agree and strongly agree; See Section 2.7.2 for explanation of Wilcoxon Signed Rank)

Table 6.14: Pre and Post results for "Teacher Effect and Teacher Effort"

Statement		SD	D	U	A	SA	Z	P
1. When a student does better than usual in science, it is usually because the teacher exerted a little extra effort	Pre	0.0%	7.7%	15.4%	73.1%	3.8%	Not sig.	
	Post	0.0%	11.5%	0.0%	76.9%	11.5%		
11. Even teachers with good science teaching abilities cannot help some kids learn science	Pre	11.5%	42.3%	15.4%	30.8%	0.0%	-2.569	.010
	Post	34.6%	42.3%	11.5%	11.5%	0.0%		
25. The low science achievement of some students cannot generally be blamed on their	Pre	0.0%	23.1%	26.9%	50.0%	0.0%	Not sig.	
	Post	0.0%	19.2%	42.3%	34.6%	3.8%		
27. Increased effort in science teaching produces little change in some students' science achievement	Pre	15.4%	34.6%	34.6%	15.4%	0.0%	Not sig.	
	Post	26.9%	38.5%	15.4%	15.4%	0.0%		
28. The teacher is generally responsible for the achievement of students in science	Pre	3.8%	26.9%	34.6%	34.6%	0.0%	Not sig.	
	Post	0.0%	15.4%	30.8%	53.8%	0.0%		
32. When a low achieving child progresses in science, it is usually due to extra attention given by the teacher	Pre	0.0%	11.5%	42.3%	46.2%	0.0%	Not sig.	
	Post	0.0%	7.7%	30.8%	53.8%	7.7%		

(SD ,D, U, A, SA = strongly disagree, disagree, uncertain, agree and strongly agree; See Section 2.7.2 for explanation of Wilcoxon Signed Rank)

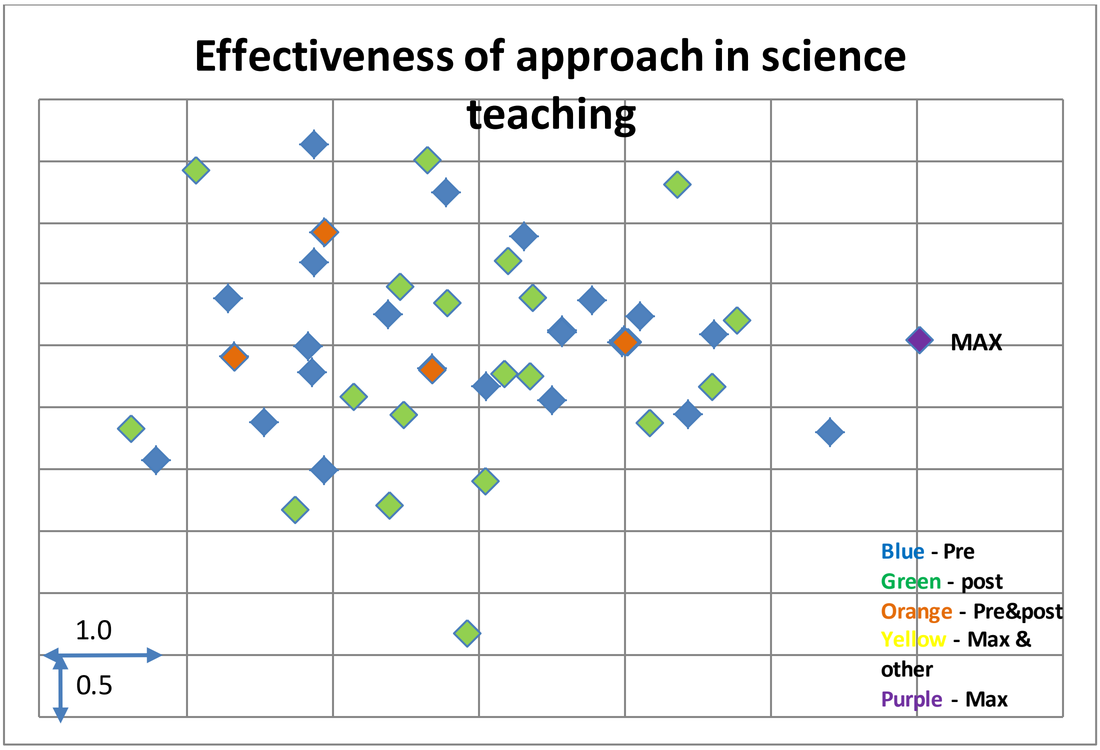


Figure 6.6: Change in Effectiveness of approach in science teaching – MDS Analysis

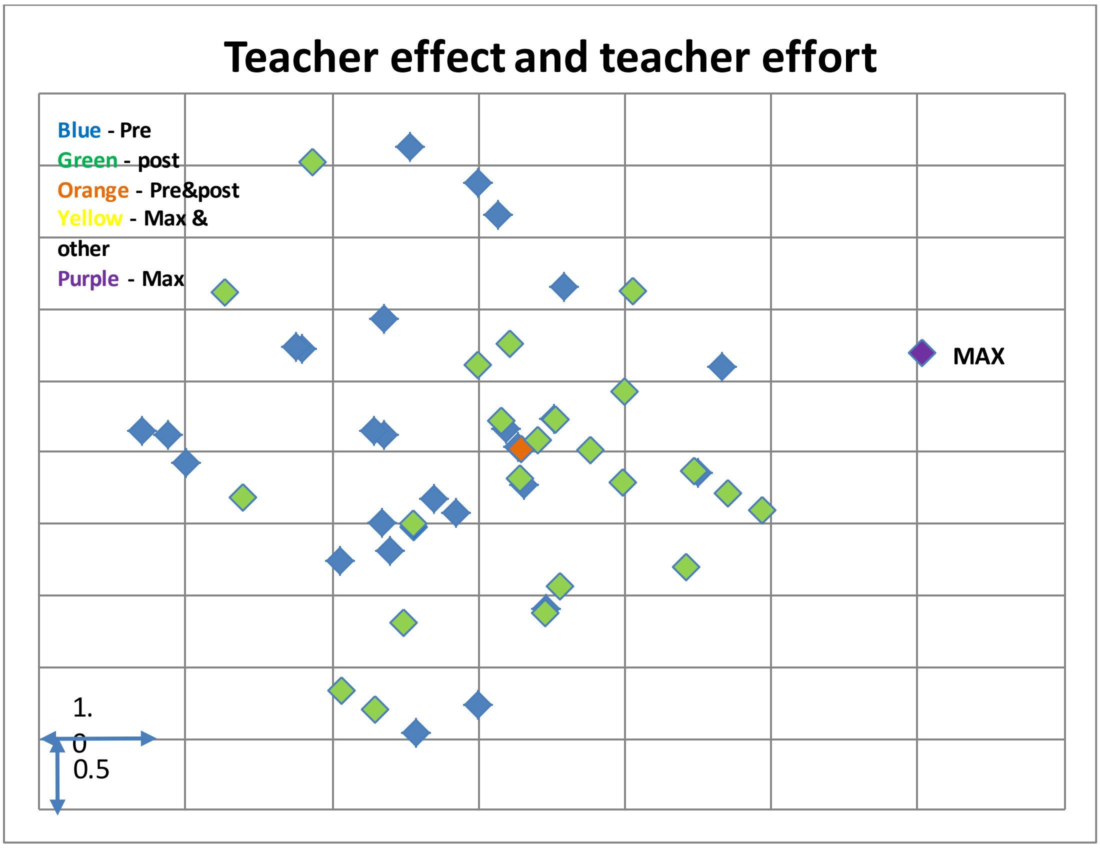


Figure 6.7: Change for Teacher effect and teacher effort - MDS Analysis

6.2.2 Content

A primary objective of this module was to teach the participants chemistry so that they are equipped to teach chemistry to students at Junior Cycle. Students demonstrated their content knowledge in their post labs and in lab tests. Notebooks were unlikely to provide accurate information about their content knowledge, as discussed in Section 6.1.2, and post labs were carried out by the participants at home so information may have been written with the aid of textbooks, their peers or the internet. So, to determine whether students have actually learned chemistry, their in-lab test results are used.

The scores from all items on tests which assess only content knowledge (not skills, attitudes towards teaching or misconceptions) were obtained for each student. The box plots showing the average, median and range of results for each test can be seen in Figure 6.8.

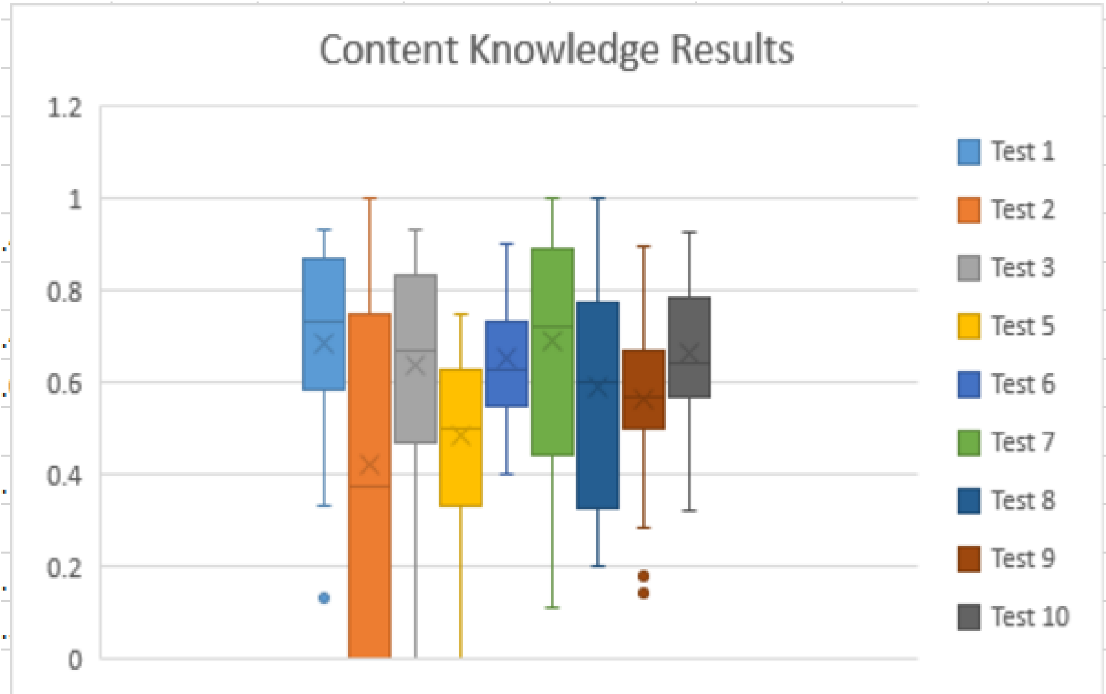


Figure 6.8: Box-plot graph showing the inter-quartile range of each set of Content Knowledge Results on 9 tests –
* The y axis indicates normalised values

The average results for each test is represented by the X contained within the box in Figure 6.8 The horizontal line in each box represents the median. Each box represents 50% of the data, 25% above and below the median line. The line or “whisker” coming from each end of the box represents the remaining 50% of the data, the upper and lower quartiles of the data. Points on the graph represent outliers. Over the course of the module the lower ranges of the data are reducing, demonstrating that there are less low scores being obtained. Depending on the test, the results varied each week. Overall, these results demonstrate that learning occurred each week, and the module successfully achieved the objective of teaching the students the required chemistry content.

The average data displayed in Figure 6.8 does not show the progress of individual students. Therefore, each student’s results for tests 1 – 10 were further analysed in the following manner: The individual student’s results for each test was plotted on a graph and the equation of the resulting trend line was obtained. The intercept value showed the result in T1 while the slope indicated if this performance was maintained (slope 0), increased (slope positive), or decreased (slope negative) over the weeks of tests. Results are shown in Table 6.15. Results are banded as natural breaks in the data occurred in these intervals.

When looking at the slope in the equation of the line, a positive slope indicates that students’ results were increasing over the course of the module, and a negative slope indicates that the results were decreasing over the course of the module. Slopes that are +/- 0.01 represents a 10% change which is considered to be staying the same rather than really changing. Each test is different so we are not expecting students’ results to increase over the course of the module. If students’ results stay the same then a “good student” stays a “good student” rather than the module failing to improve or teach the students.

The slopes tell us that the students who are poorer at chemistry (the <0.4 and 0.4 – 0.6 bands) have increased over the course of the module or remained the same. However, the upper grouping (0.8 – 1.0) either remained the same or decreased during the module. Interestingly, none of the five participants who have completed chemistry for the leaving certificate were located in the upper grouping. All participants were located in one of the lower groupings (<0.8). Another point worth noting about the upper grouping is that only two engaged with all of the feedback provided on their post labs. Further engagement could have improved their results. Students maintained their progress throughout the module.

Table 6.15: Changes in participants' content knowledge

Intercept value (y)	Total students	Number of students		
		Slope positive	**Slope negative**	**No change**
0.8 < y ≤ 1.0	5	0	4	1
0.6 < y ≤ 0.8	10	1	4	5
0.4 < y ≤ 0.6	9	4	1	4
≤0.4	10	8	0	2

6.2.3 Inquiry Skills

Development of the PSTs' inquiry skills was determined from their in-class tests, post labs, project proposal, and their project proposal critique which was carried out in-lab. Two particular skills were focussed on and these shall be discussed separately. These are the skills of planning investigations and critiquing experiments.

6.2.3.1 Planning Investigations

The skill of planning investigations includes producing a logical plan for an experiment, identifying and controlling the variables involved, and modifying the experimental plan whenever appropriate. The skill of planning investigations was a major focus within the laboratory sessions. This section highlights the development of this skill over the course of the module.

One such activity where planning investigations was a focus, was the separation of seeds activity discussed in Section 5.4.4. The following is an excerpt from the Researcher's Journal from this activity:

"...After some initial delay where students seemed uncomfortable with committing their plans to paper, the students engaged well with the separating seeds

experiment and actually seemed to enjoy trying to obtain pure samples. Since there was no equipment laid out, there was plenty of variety in the plans that the students generated. Separations were carried out using funnels and sieves, holes were made in filter paper, and interestingly one group attempted to separate their seeds by floatation, by changing the density of water using salt. Discussion was required however to highlight that they were exploiting properties of their substances to separate their seeds. This was a suitable activity for students to begin planning investigations and to develop their skills." – Researcher Journal, Lab Session 2.

Another important planning investigations activity was the "Separation Challenge" activity carried out by the students. The following is an excerpt from the Researcher's Journal from this activity:

"…Having separated students into groups as planned and pointing out the mixtures they had to work with, there was the usual issue of having to write down what they were planning to do. The problem here is not that they can't plan their separation (because they can) they just seem to be uncomfortable with potentially writing the wrong answer. Either way, once their plans were written they set about separating their mixtures. This experiment worked very well as they had to use properties for some that they had not really encountered before such as magnetism and solubility in organic solvents for the candlewax. They really had to think through what property they were using, what order they were carrying things out, and what they could actually improve on. I think that the students definitely demonstrated their ability to plan an investigation here." – Researcher Journal, Lab Session 8.

Over the course of the module, the different questions required the participants to demonstrate various aspects of the skill of planning investigations. The participants' scores for planning investigations were tracked over the course of the module. The scores for particular activities (as outlined in Section 6.1.3.1) were compiled for each student and then used as inputs for MDS analysis.

Figure 6.9 represents the position of the participants' planning investigations skill over the first eight weeks of the programme (see Section 6.1.3.1). The max point indicates the position of fully demonstrating the skill of planning investigations in these items. For example, for post lab 2 the participants would need to describe an appropriate method, include all of the materials required, and describe each step clearly, to fully demonstrate the planning investigations skill in this post lab.

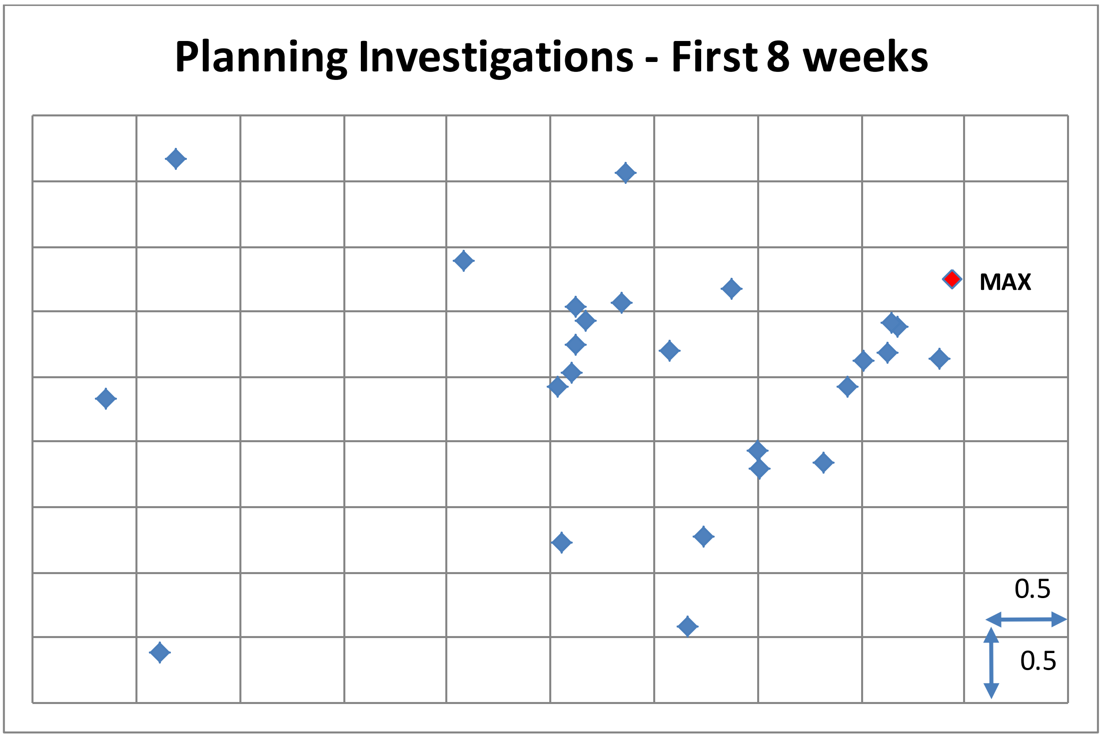


Figure 6.9: Evaluation of Planning Investigations Skill in first 8 weeks – MDS Analysis

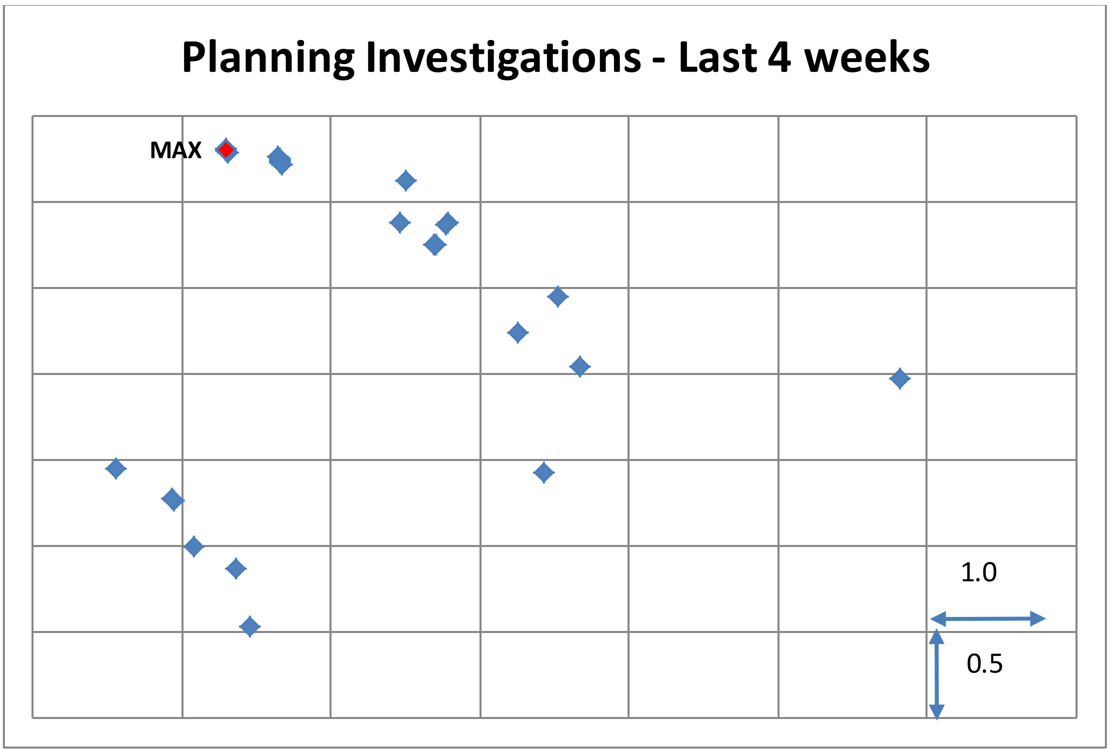


Figure 6.10: Evaluation of Planning Investigations Skill in last 4 weeks – MDS Analysis

The MDS graph in Figure 6.10 represents the position of the participants' planning investigations skill over the remaining weeks of the programme. Some participants are achieving similar results and are "hidden" behind other points on the graph including the max point. There are 6 participants hidden at the max point and five located in the group to the right of that point. From this we can see that there are now participants who are demonstrating the skill of planning investigations in their work and many of the participants have moved closer to this max than were there initially. It is clear that over the course of the module the participants' planning investigations skill moved closer to the max. There are more participants clustered around the max than were there in the first half of the programme.

To determine if a strong level of chemistry content knowledge related to their ability to plan investigations, the data was analysed using correlations. Looking at the areas where correlations are present, there are links between the participants' planning investigations results on individual assignments and their average content knowledge result (Table 6.16). In each case, higher content knowledge was linked to higher planning investigations skill.

Table 6.16: Relationships between Planning Investigations and Average Content Knowledge

PI and Tests	R	P
T2(PI) & CK average	.548	.001
T6(PI) & CK average	.375	.029
T7(PI) & CK average	.473	.008

6.2.3.2 Critiquing Experiments

The participants' skill of critiquing experiments was developed over the course of multiple activities.

Following the first submission of the participants' project proposal, participants were split into groups of four and asked to identify key aspects that should be included in a project proposal. Initially they did this individually, and then as a group they discussed and refined their individual ideas into one set of criteria per group.

Once their criteria had been established, each participant was given one of their peers' project proposals to critique based on their group agreed criteria. The majority of the participants critiqued individually, however one group of four (Group 1) chose to critique as a group.

"…There was initially some push back from the students when asked to critique their peers. They had no problems generating their criteria, but they were uncomfortable with critiquing their peers and also being critiqued by those in their class. They really just wanted me to critique their proposals for them. They had to be reminded that as future teachers, providing feedback on student work would eventually be a major part of their job! After some encouragement they began their critique and eventually got into the swing of it. Everyone in the class critiqued an assignment individually and it was actually a very effective task for developing this skill because the students were particularly invested in the outcome!" – Researcher Journal, Lab Session 10.

The first part of this critique involved the participants developing a set of criteria for key aspects that should be contained within a science project proposal. Across the 32 participants who completed this particular section, there were numerous suggestions put forward as to what should be included in a project proposal.

These aspects were used for much of the analysis of this section. The suggestions made by the group were analysed by the researcher (as detailed in Section 6.1.3.2) and themes were determined. The ten themes identified are layout, introduction or background, procedures and experiments, fair test and variables, hypothesis and questions, safety, limitations and accuracy, results, evaluation of results, and teaching aspects. The criteria suggested by the students and the themes are shown in Figure 6.11.

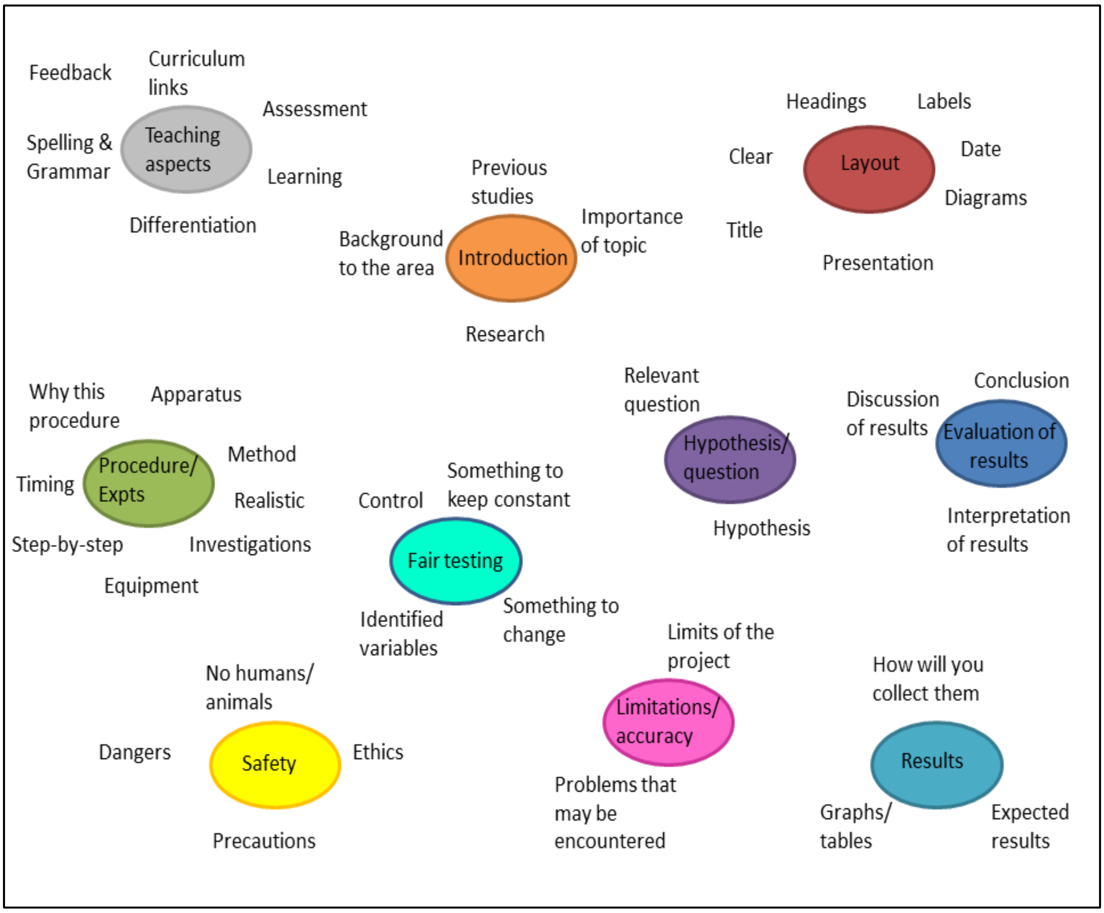


Figure 6.11: Project Critique Criteria

After developing these criteria individually, participants came together in eight groups (G1 – G8) of four to discuss and decide upon what they considered to be necessary elements in their criteria. This became their group agreed criteria, and the elements that made it into this are shown in Table 6.17.

Table 6.17: Criteria included by each group

	Layout	Introduction/ Background.	Procedure	Fair test	Hypothesis	Safety	Limitations	Results	Evaluation of results	Teaching elements
G1	X	X	X	X		X		X	X	X
G2	X	X	X	X	X					
G3		X	X	X	X		X	X	X	
G4	X	X	X	X	X	X	X	X		
G5		X	X					X	X	
G6			X		X					
G7			X	X	X	X		X		X
G8		X	X	X	X			X	X	

*Where G1 – G8 refers to groups 1 to groups 8

It is important to note that not all criteria were included by each group, but all groups focussed on procedure. More groups mentioned procedure, fair testing, hypothesis and results, but the lack of consideration for the safety and limitations is worrying.

The most popularly referred to element included in their criteria discusses details about the procedure and experiments to be included in the projects. The limitations and accuracy of the experiment is the least referred to aspect in the participants' agreed upon group criteria.

The participants critiqued one of their peer's project proposals based on their agreed criteria. The participants from Group 8 are not included in the analysis for as this group provided feedback together instead of individually. The researcher used the participants' group criteria to critique each project as they were supposed to critique it. It was found that only 21% of the participants provided feedback to their peers based on their agreed criteria. The remainder, who did not apply their critique correctly, either critiqued additional elements or left out elements (results shown in Figure 6.12). Each graph shows the number of participants who left out particular aspects of the feedback, or provided additional feedback.

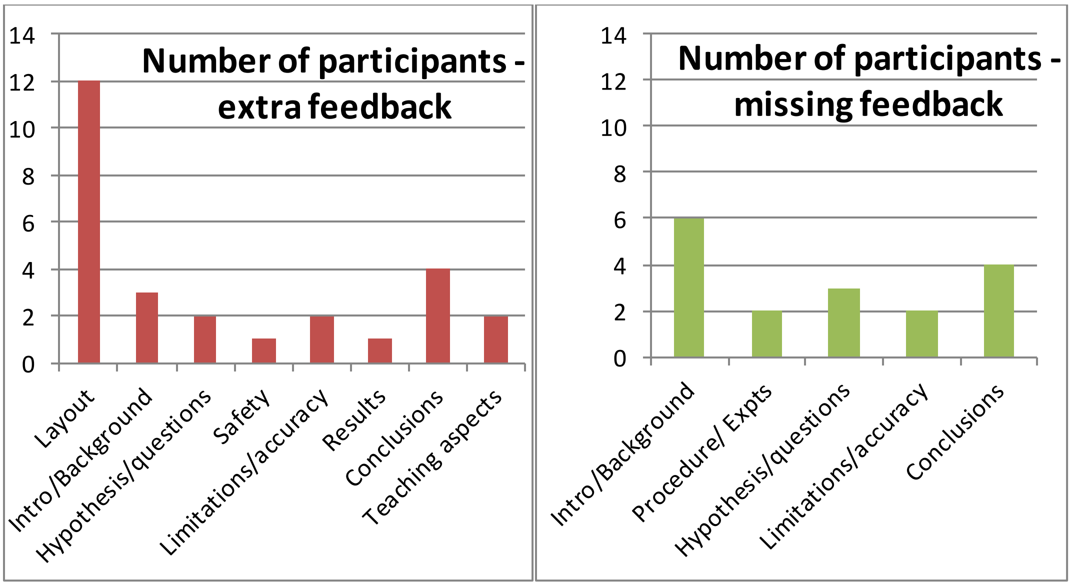
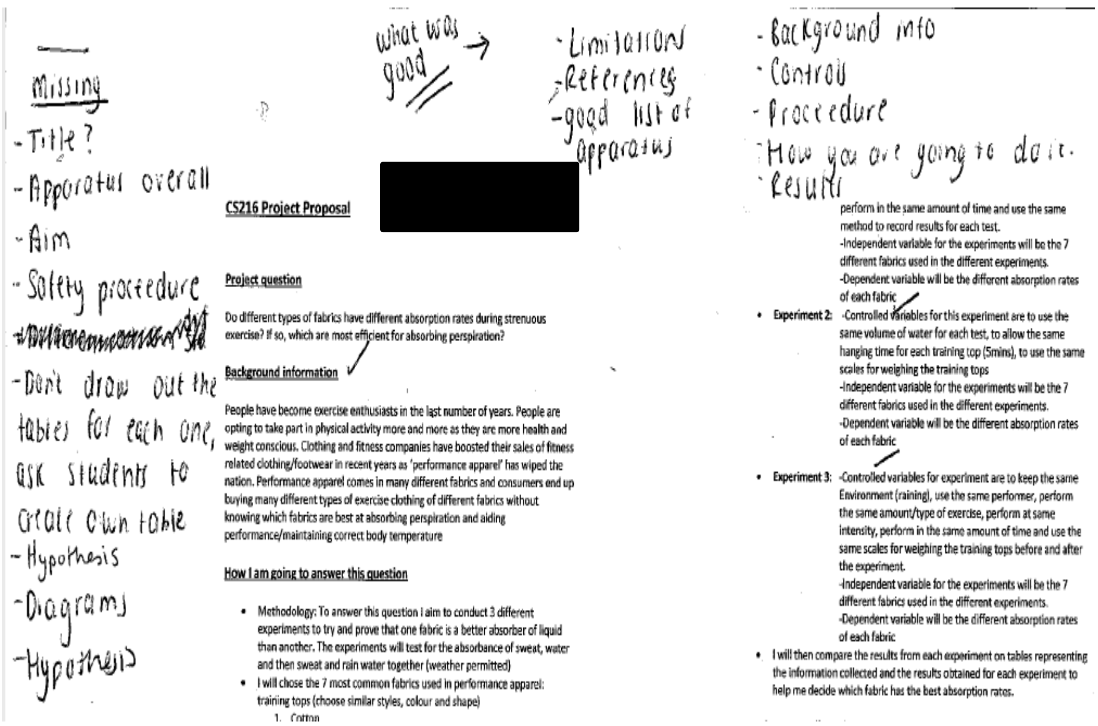


Figure 6.12: Critiquing Project Proposals – Missing and additional critique

Looking at Figure 6.12, it is clear that how the participants' actually critiqued the project proposals and how they should have been critiqued are not quite the same. 36.2% of feedback provided by the participants was on topics not included in their criteria. The main type of feedback that was provided additionally was on their layout, which was feedback at a very basic level. The participants were missing 15.5% of the feedback they should have provided. Overall, they were more likely to provide additional feedback on topics rather than omit certain aspects, which is positive. Feedback on the participants' introduction and background was the form of feedback which was included in their criteria, but omitted from their feedback the most.

Interestingly, the nature of the feedback provided by the participants was diverse. Feedback ranged from one or two words of guidance, to comprehensive bullet points detailing the steps that should be taken next by the participants. However, the majority of the feedback included was minimal and lacked detail on students' next steps. See Figures 6.13, 6.14, and 6.15 for examples of procedural, extensive and very poor student feedback, respectively.



CS216 Project Proposal [redacted]

Project question

Do different types of fabrics have different absorption rates during strenuous exercise? If so, which are most efficient for absorbing perspiration?

Background information

People have become exercise enthusiasts in the last number of years. People are opting to take part in physical activity more and more as they are more health and weight conscious. Clothing and fitness companies have boosted their sales of fitness related clothing/footwear in recent years as 'performance apparel' has wiped the nation. Performance apparel comes in many different fabrics and consumers end up buying many different types of exercise clothing of different fabrics without knowing which fabrics are best at absorbing perspiration and aiding performance/maintaining correct body temperature

How I am going to answer this question

- Methodology: To answer this question I aim to conduct 3 different experiments to try and prove that one fabric is a better absorber of liquid than another. The experiments will test for the absorbance of sweat, water and then sweat and rain water together (weather permitted)
- I will chose the 7 most common fabrics used in performance apparel: training tops (choose similar styles, colour and shape)
    1. Cotton

perform in the same amount of time and use the same method to record results for each test.
-Independent variable for the experiments will be the 7 different fabrics used in the different experiments.
-Dependent variable will be the different absorption rates of each fabric

- **Experiment 2:** -Controlled variables for this experiment are to use the same volume of water for each test, to allow the same hanging time for each training top (5mins), to use the same scales for weighing the training tops
-Independent variable for the experiments will be the 7 different fabrics used in the different experiments.
-Dependent variable will be the different absorption rates of each fabric
- **Experiment 3:** -Controlled variables for experiment are to keep the same Environment (raining), use the same performer, perform the same amount/type of exercise, perform at same intensity, perform in the same amount of time and use the same scales for weighing the training tops before and after the experiment.
-Independent variable for the experiments will be the 7 different fabrics used in the different experiments.
-Dependent variable will be the different absorption rates of each fabric
- I will then compare the results from each experiment on tables representing the information collected and the results obtained for each experiment to help me decide which fabric has the best absorption rates.

Figure 6.13: Example of procedural Student feedback

→ Really well drawn up. :)
→ Relevant and has cross curricular links.
→ Good background.
→ I would compare the results you intend to obtain against a game environment. i.e. will the hurley be in contact with the pitch surface for 2-3 hours like you have in Ex. 2.
- or will rainfall have the same effect of leaving the hurley to soak for an hour?
→ I would have samples of ash and cultec hurleys instead of a full hurley for each group as space and resources may be limited.
→ Reference any sources info was obtained from.
→ Well researched, found it quite interesting !!

Figure 6.14: Example of extensive Student Feedback

Record the mass of the tooth and compare it to the original mass of 2g. Have there been any changes? If so, what drinks caused changes.

Think about the components of each drink. What is in the drinks that caused these changes to occur? Has a reaction occurred?

Design a results table to record all the results from this week of the investigation. Below is an example of a results table. Different groups will have different tables depending on what they see happening.

	A	B	C	D	E
Observations					
Change in mass					
Component of drink to cause change(sugar, citric acid etc)					
Has a reaction occurred?					

Add diagrams more visual.

Part (ii) Place 2g Calcium into 5 test tubes and label them A-E. Place them in a rack.

Add 10ml lemon juice to test tube A, 10ml vinegar to test tube B, 10ml orange juice to test tube C, 10ml Coca Cola to test tube D and 10ml milk to test tube E. Make sure to use a clean dropper for each drink.

Observe initial changes and if there are any signs of a reaction happening and also the pH

Cover test tubes with stoppers and leave to sit for two weeks in the fridge.

Figure 6.15: Example of very poor Student Feedback

6.2.4 Teaching Approach

Information about how participants would consider teaching particular chemistry topics was obtained from post lab assignments. In many of the assignments, the students were asked to outline how they would teach a particular concept taking account of the potential misconceptions. These assignments were analysed and rated on a scale from 1 to 6, ranging from chalk and talk type teaching to open inquiry (see Section 6.1.4).

1. Chalk and talk
2. Demonstration/ activity
3. Confirmation inquiry
4. Structured inquiry
5. Guided inquiry
6. Open inquiry

The results were then combined for the assignments in the first 6 weeks and the last 6 weeks and subjected to MDS analysis. The results have been split into evidence from the first six weeks and the remaining weeks so as to view any differences between the beginning and the end of the module. Evidence was obtained from PL 2, 3, 5 and 6 for the first 6 weeks and evidence is from PL7 and their misconception assignment for the last 6 weeks. Figure 6.16 represents the position of the participants' teaching over the first six weeks of the programme. Change in attitudes towards teaching takes time, and participants will need to see evidence of the benefits of this approach for themselves. These benefits may not be apparent to them in the early stages of the module. L1 – 6 on Figure 6.16 provides a position with which to measure the position of the teachers as each relates to a point representing complete use of a particular level, for example L3 is an input indicating confirmation inquiry for PL2, 3, 5 and 6.

It is clear from Figure 6.16 that the majority of the participants are located between L1 and L3, indicating that they would teach using chalk and talk methods and teacher demonstrations or activities. Some of the participants which are closer to

L3 have included some suggestion of confirmation inquiry, but not for each teaching example.

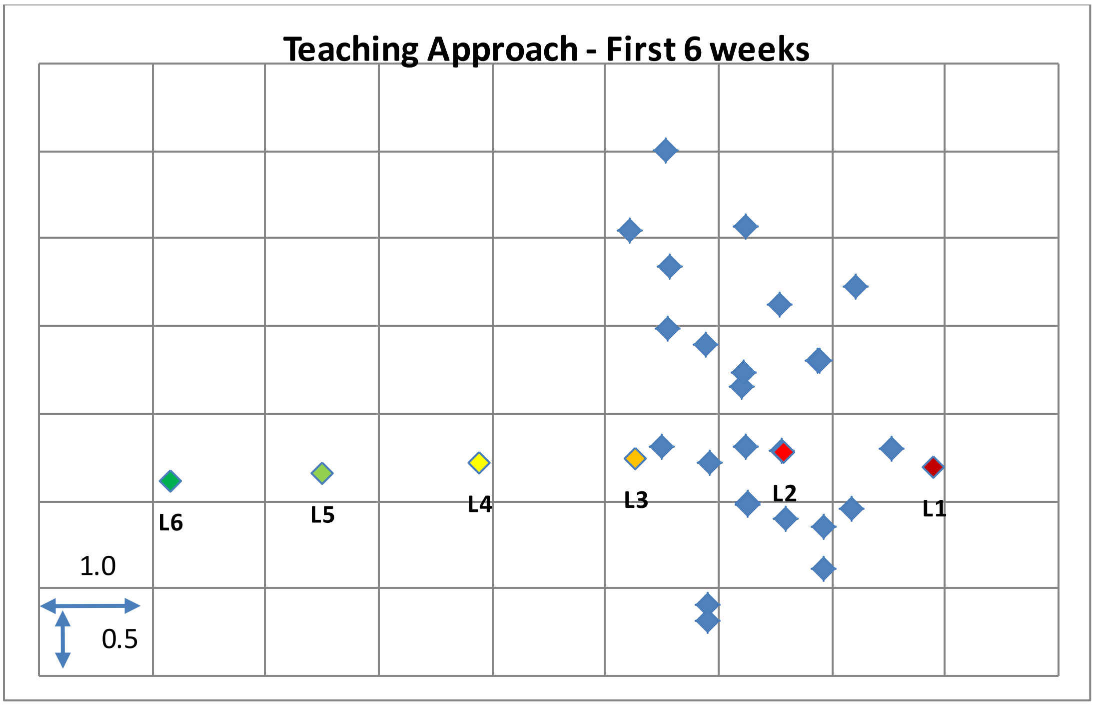


Figure 6.16: Evaluation of Teaching Approach in first six weeks – MDS Analysis

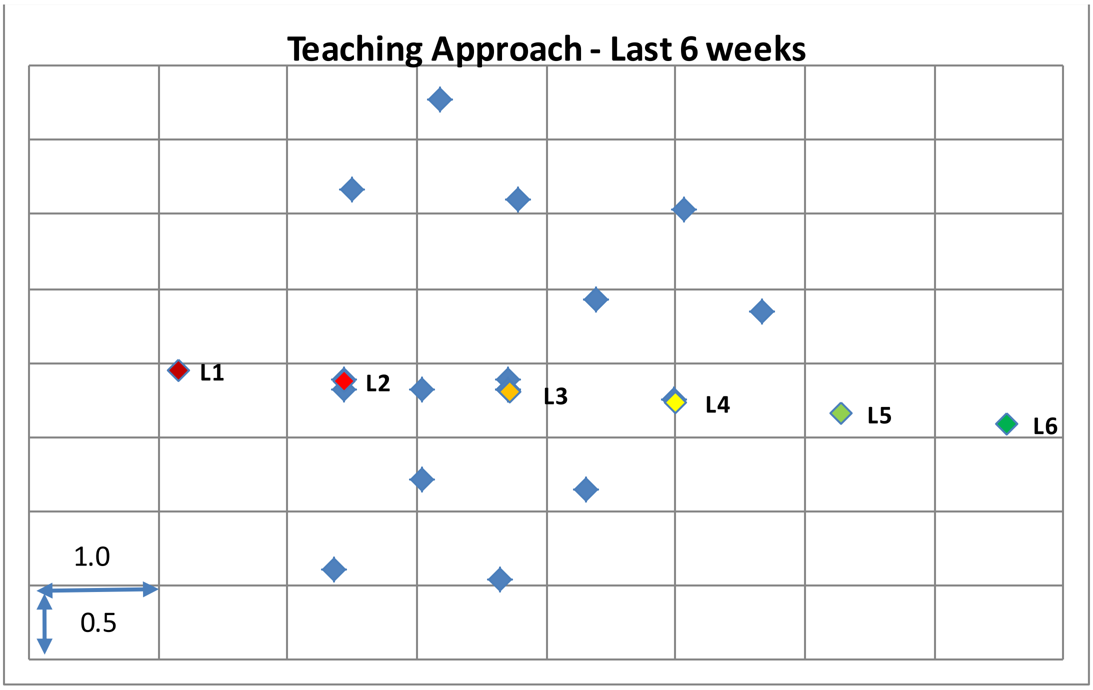


Figure 6.17: Evaluation of Teaching Approach in last six weeks – MDS Analysis

Figure 6.17, shows the teaching approach of the participants in the second half of the module. The positions of the participants have changed and became somewhat more inquiry oriented. From Figure 6.17 it is clear that there are less participants between L1 and L2, indicating that they consider doing chalk and talk teaching less than previously. There are also much more participants located between L3 and L4 which shows that more of the PSTs were moving beyond confirmation inquiry and towards structured and guided inquiry.

This result was probed further using the method employed in Section 6.2.2 for content knowledge. The participants' values for their approach on each assignment were graphed and a trend line was created for each graph. The equation of the line was determined for each student's results graph. When looking at the slope in the equation of the line, a positive slope indicates that the numerical value representing the students' approach was increasing over the course of the module, and a negative slope indicates that the value was decreasing over the course of the module. Therefore, a positive slope would indicate that a participant has indicated using a more inquiry approach as the laboratory module progressed. Slopes that are +/- 0.01 represents a 10% change which is considered to be staying the same rather than really changing.

The results showed that of the 34 students, only 9 students moved away from suggesting inquiry instruction or their suggested approaches remained the same. The remaining 25 students all showed positive trends suggesting more inquiry-oriented instruction within their assignments. This confirms the previously discussed results comparing the approaches taken in the first six weeks to the last six weeks.

6.2.4.1 Subject Effect

Only five of the participants had taken chemistry for their leaving certificate. In their first assignment where they discussed how they would teach a topic, none of the five indicated a chalk and type level class. Three of these presented a structured inquiry approach and one suggested a guided inquiry approach. Those without chemistry were more likely to have a demonstration/activity approach to teaching chemistry.

To confirm that the effect was a result of having chemistry and not due to having two science subjects, all other participants with two science subjects (e.g. physics and biology, agricultural science and biology, etc.) were examined. Not one of these six additional participants provided an example of structured or guided inquiry in their first submission. In fact, these participants did not start including structured or guided inquiry until the second half of the module. This strengthens the position that having more background knowledge of the subject (chemistry) makes the participant more comfortable with including inquiry instruction in their classroom.

6.2.4.2 Relationship with views towards science teaching

The participants' teaching approach is likely impacted by their own views about science teaching. To determine any links between their views and how they approach teaching, correlations were carried out. The participants' ideas about how they will teach from Section 6.2.4 and the findings of the first questionnaire (Section 6.2.1) completed by the participants are related and results shown in Table 6.18. They were unsure about whether they would feel confident with letting their students come up with their own questions, investigations, and conclusions. The correlations show that the more ineffective they believe they will be at monitoring science investigations and guiding their students, the more likely they are to discuss conducting chalk and talk or demonstration type classes instead of inquiry type classes. Interestingly, the less they understand science, the less likely they are to conduct inquiry oriented lessons. There is a relationship between their teaching approach and keeping students on task in the classroom where those who are more likely to do some form of inquiry activity consider keeping students focussed their highest priority in class.

The comparisons between the initial questionnaire results and the participants' teaching approach at the first half of the module demonstrate a relationship between their understanding of science and what type of teaching they discuss carrying out in their classroom. However, this relationship is not present when looking at the results of the second half of the module and their follow up questionnaire.

Table 6.18: Relationships between their teaching approach at the beginning and their pre-questionnaire

Statement	Post lab	R	p
I think that I will not be very effective monitoring science investigations	PL3	-.391	.048
I don't understand science at all	PL3	-.427	.030
I think that I will feel very comfortable guiding students, listening to their questions, and supporting their investigations	PL5	-.607	.001
I think that I will be at ease allowing my students to develop their own explanations for their findings	PL6	419	.037
Keeping students on task will be my highest priority in the classroom	PL6	.426	.034

6.2.4.3 Conceptual Assignment

The conceptual assignment was designed to engage the participants both in the identification of misconceptions in chemistry that they may have, but also to have them reflect on how they would teach this area so that their own future students would not develop these issues. Each student received their own individual misconception task that they were asked to discuss how they would teach the topic so that their students did not develop this misconception. This was also the last task that students were to complete where they discussed any teaching approach.

When specifically tasked with planning to teach a topic in a way that students would not develop misconceptions, the majority of students did not suggest chalk and talk methods or a teacher demonstration. In fact, only one student believed that the chalk and talk method would be suitable for dealing with their misconception. Importantly, the majority of students suggested confirmation, structured, or guided inquiry as their chosen method for dealing with misconceptions (Figure 6.18). This speaks to the level of confidence that the participant had in the inquiry approach carried out within these laboratory sessions.

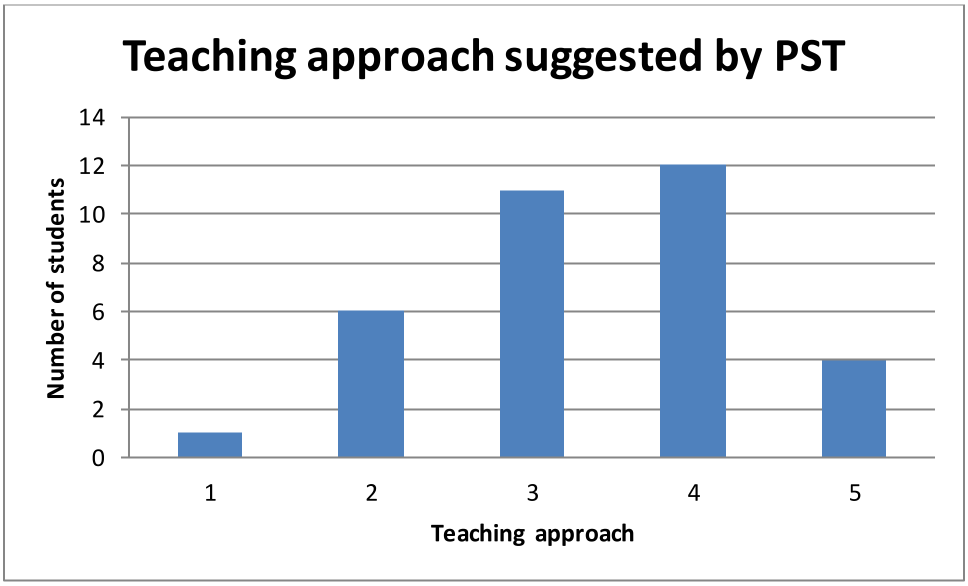


Figure 6.18: Teaching approach (levels 1 – 6) suggested by participants for misconceptions assignment

6.2.5 Visualisations

One of the key aspects included within this module was a focus on visualisations. Visualisations have been successfully incorporated into this module. The participants were asked to include molecular level diagrams wherever appropriate within their notebook write ups. Representations were also produced as tasks during certain laboratory sessions. The participants created their own visualisations representing their knowledge and views of concepts during the laboratory sessions, and the instructors used these to identify any misunderstandings they had and to initiate discussions on the topic.

A key example of this was when students were asked to represent solids, liquids, and gases at a molecular level. Samples of students' drawings are shown in Figures 6.19 and 6.20. Depictions such as these gave rise to debates on what is the difference between a liquid and a gas when the participants have represented both as having large amounts of space between the particles. Issues in students' understandings of states of matter could be addressed as a result. For solids, liquids, and gases (Figure 6.19), the only way to understand the differences between these states at a molecular level is to use representations and these are necessary to avoid developing misconceptions.

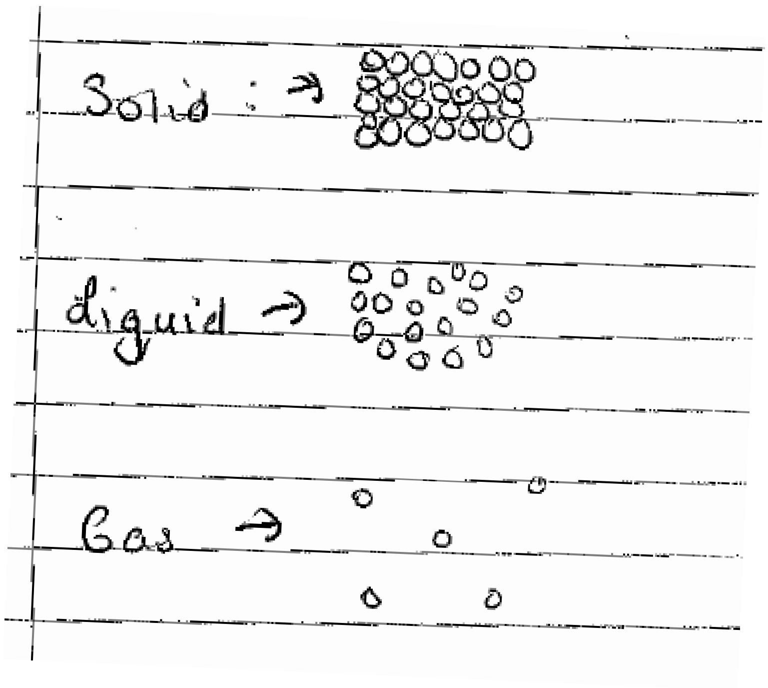


Figure 6.19: Student representation of different states of matter at a molecular level

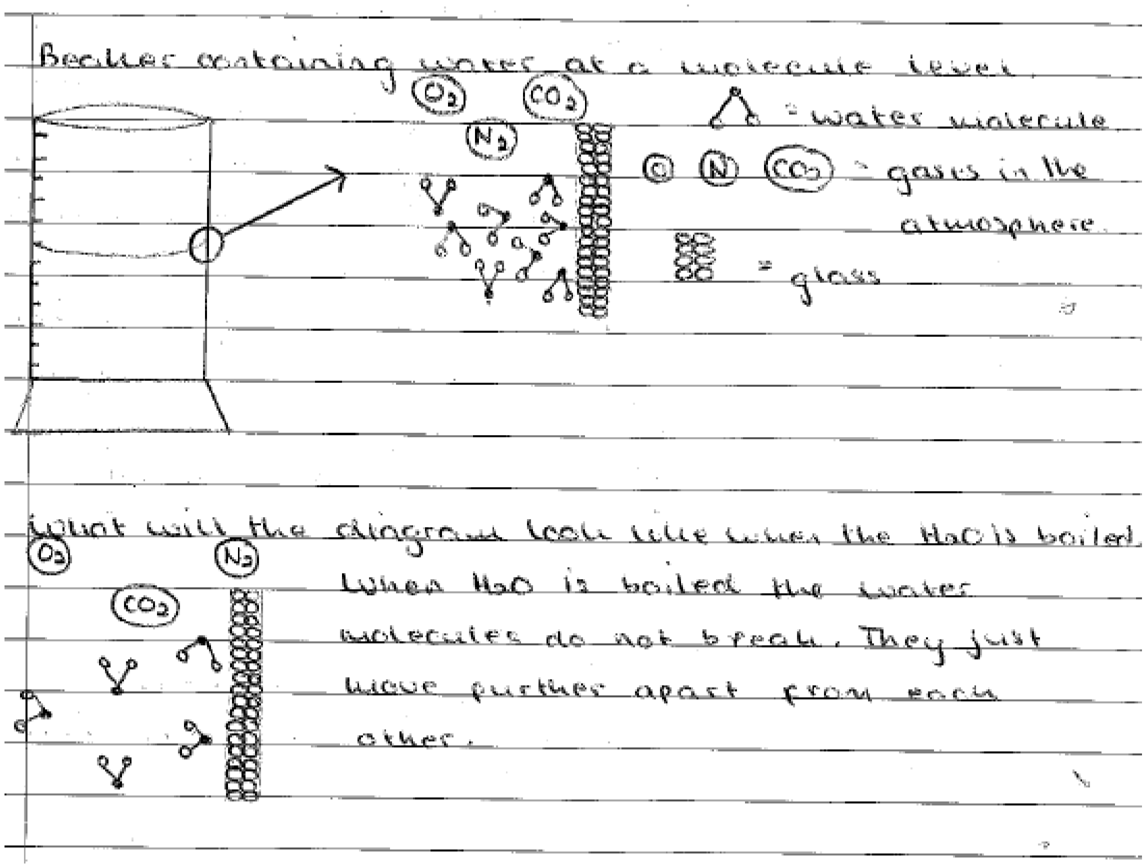


Figure 6.20: Student representation of different states of matter using various symbols

Additionally, representations such as that shown in Figure 6.20 include three different ways of representing particles in the one image. This allowed for discussions in terms of teaching this topic, and how the mixing together of these symbols could potentially confuse students further and develop misconceptions.

The importance of how we represent certain concepts and the differences between our various symbols in chemistry were discussed throughout the module. Another example is shown in Figure 6.21 where a student demonstrates how a molecule is represented both at the 2D and 3D level.

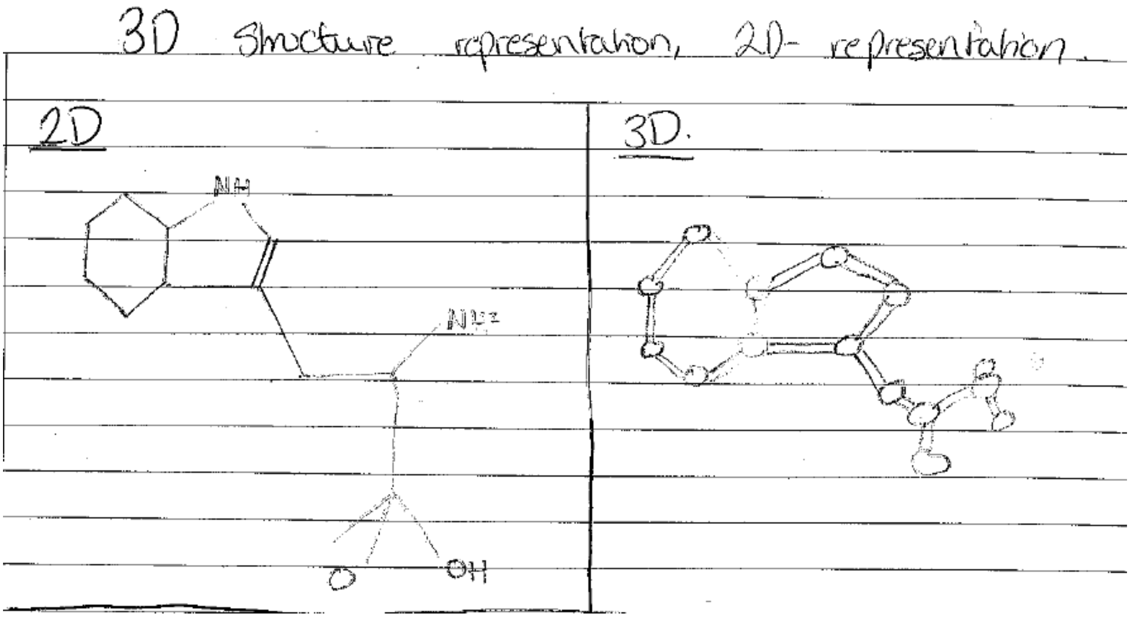


Figure 6.21: Student representation of a 2D and 3D depiction of the same molecule

In addition to using visualisations to determine any issues that students may have and discussing visualisations in relation to the participants' future teaching, the participants created representations to aid them in understanding and explaining some of the experiments that they were carrying out. For example, Figures 6.22, 6.23 and 6.24 demonstrate how students used visualisations to represent what was occurring within their experimental work.

Figures 6.22 and 6.23 relate to two different separation activities that the students carried out. Figure 6.22 demonstrates how this student represented what they were hoping to achieve within the experiment that they had planned where they attempted to separate seeds, and Figure 6.23 is a representation created by a student trying to explain why tea can't be separated using a filter from water, even though solid tea is left behind in the tea bag. Figure 6.24 is from the SAP experiment and the student is attempting to visualise what is happening at a molecular level that would cause there to be a difference between water and salt water in their experiment.

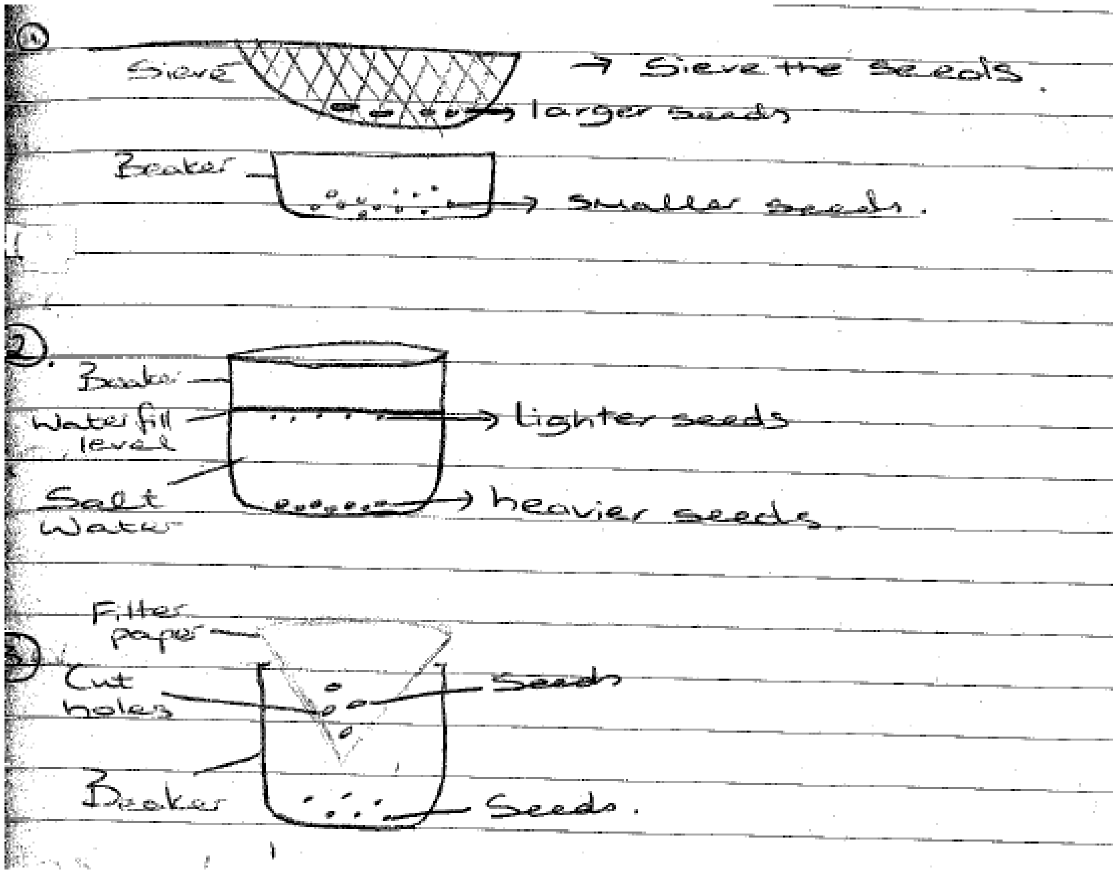


Figure 6.22: Student representations of separating seeds at a macro level

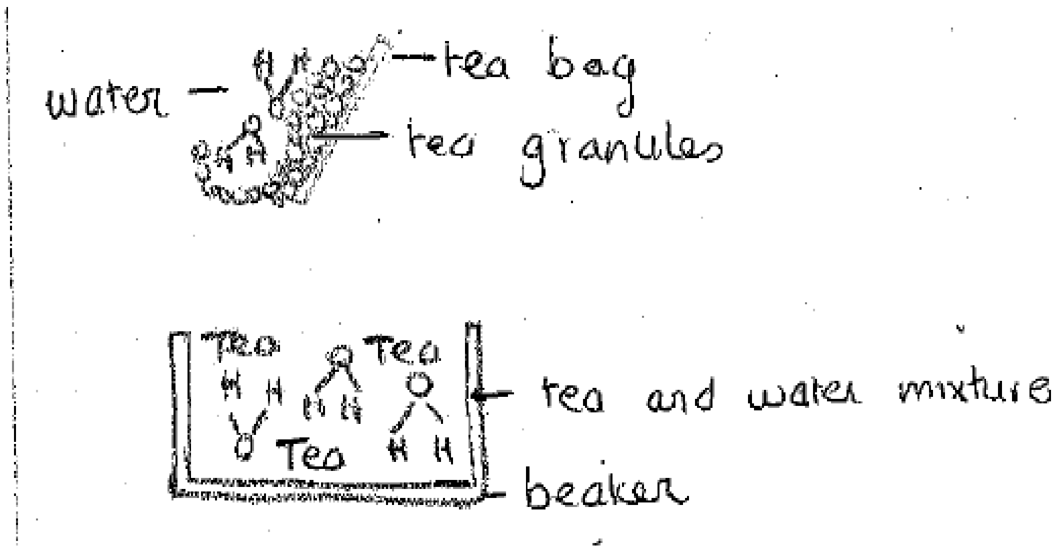


Figure 6.23: Student representation of solid tea leaves and dissolved tea

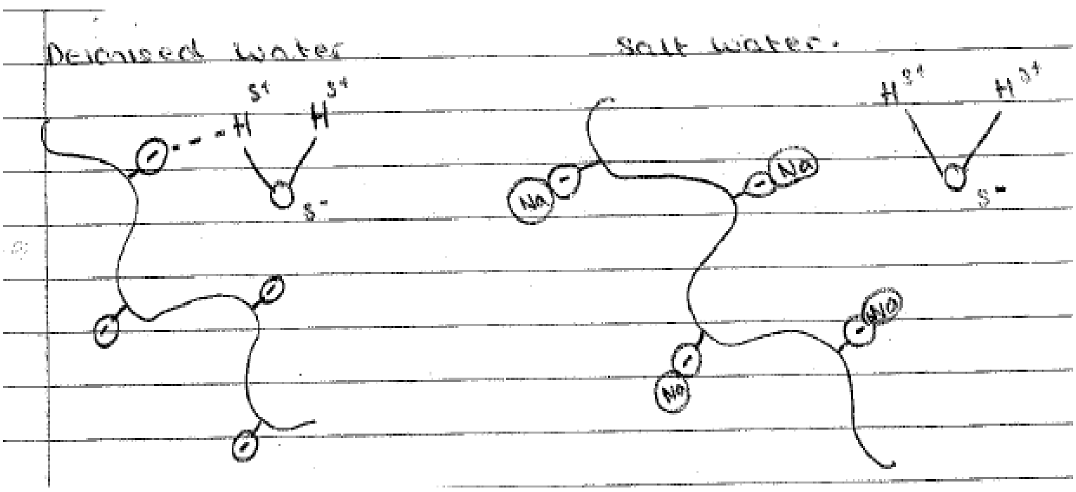


Figure 6.24: Student representation of the impact of ionic solutions on SAP

It is clear that visualisations were a sustained aspect of the module. Visualisations were implemented successfully in different contexts throughout such as states of matter, and solubility. The participant dealt with representations at the macro and sub-micro levels throughout the course of the module. The students engaged with the generation of models and representations for the benefit of their own understanding and so that the instructors could identify any issues they were having and initiate discussions in this area. The students' visualisations themselves were not analysed.

6.3 Conclusions

The aim of this intervention was to prepare pre-service teachers for teaching through inquiry in the future by impacting on their understanding and views towards inquiry teaching. Pre-service teachers took part in a module which was to provide opportunities for the participants to experience inquiry first-hand, learn content and develop skills through inquiry, and experience formative assessment.

Evaluation was carried out based on the participants' views towards science teaching, the content knowledge gained, the inquiry skills shown, and the teaching approaches demonstrated. Questionnaires were developed to collect students views and analysed for statistical significant findings and MDS was used to illustrate similarities and differences between responses, and changes in participants responses to statements. The impact of the implementation of the designed intervention was evident across six aspects:

6.3.1: Views towards Science Teaching

Participants gained confidence in giving control for the experimental work to the students, which is similar to the results shown in Phase 2, and expressed increased understanding of science and the scientific research process. They were also more confident in their abilities to support students in their development of research questions and investigations.

Their confidence with teaching through inquiry has increased over the course of the module. They are more confident teaching science in their classroom and they enjoy science more. It has previously been shown that TEPs where teachers are immersed in authentic inquiry will more likely prepare teachers to implement inquiry instruction (Capps & Crawford, 2009). Having experienced the benefits of increased student control during their laboratory sessions, the participants are now more comfortable with this approach and confident with teaching this way.

However, over the course of the module participants' views towards the impact of an effective approach in science teaching did not change. This indicates that they have strongly held views of the impact of teachers' efforts and pedagogies on students. A greater emphasis may have to be placed on the impact of different methodologies to highlight their impact and the impact of teachers on students. As not all of the activities were inquiry based, the PSTs could be asked to consider what the benefits of different methodologies are in different situations, or why a teacher would choose one option over the other.

This module was successful in developing the confidence of participants with no teaching experience. By adapting Guskey's approach (Guskey, 2002) where teachers need to trial a method and see the impact on students' learning and consequently change their attitudes and beliefs, to a PST-suitable approach where they experience the method as students and see the impact on their own learning and development, they have developed a positive approach towards inquiry. Experiencing inquiry and inquiry assessment first hand has clearly benefitted the students and this method should be considered in future PST education programmes.

6.3.2 Content Knowledge

This module was a chemistry lab module and one of the aims of the module was to teach the participants chemistry content knowledge. The module was particularly successful at developing the content knowledge of those who started off quite poor at chemistry, and was successful in increasing the content knowledge of the rest of the participants.

6.3.3 Inquiry Skills

Over the course of the module, the participants demonstrated an increased ability in planning investigations over the 12 weeks. In addition, participants with higher content knowledge were shown to have better planning investigations skill.

For the skill of critiquing experiments the participants first worked in small groups to identify criteria that should be used to evaluate experimental work and ten different criteria were proposed. Most groups identified procedure, fair testing, hypothesis and results, and less consideration was given to aspects such as safety and limitations. However the PSTs failed to utilise their own selected criteria and provided minimal feedback in terms of next steps in learning to their peers.

6.3.4 Teaching Approach

Over the duration of the module the participants showed an increase towards inquiry-oriented instruction within their assignments. The participants that had more of a background knowledge of the subject (chemistry) exhibited more comfort with including inquiry instruction in their classroom. This study has shown that the less they understand science, the less likely they are to conduct inquiry oriented lessons. and the more ineffective they believe they will be at monitoring science investigations and guiding their students, the more likely they are to discuss conducting chalk and talk or demonstration type classes instead of inquiry type classes. Interestingly, the participants who were more likely to do some form of inquiry activity consider keeping students focussed their highest priority in class. The participants also believe that inquiry approaches are also appropriate for dealing with misconceptions.

6.3.5 Visualisations

Visualisations have been successfully incorporated into this module. The participants used molecular level diagrams and representations in various laboratory sessions. The participants created their own visualisations representing their knowledge and views of concepts during the laboratory sessions, and the instructors used these to identify any faulty understandings they had and to initiate discussions on the topic.

6.3.6 Limitations

Despite the positive results, this study comes with limitations. The in-depth nature of the case-study approach which is embedded within a specific environment means that the findings from a single case study are not very generalizable (Yin, 2014). Additionally, why the results indicate a positive move towards inquiry instruction, it is impossible to say at this stage how the participants will actually go on to teach in their classrooms.

Chapter 7 – Conclusions and Implications

The overall question for this study was "What is the influence of focussed teacher education programmes (TEPs) on pre-service teachers' (PST) inquiry and assessment approaches?" This study was divided into three phases, which are:

1. Determination of PSTs' understanding and views of inquiry practices, and how these change following an inquiry teacher education programme.
2. Determination of PSTs' understanding and views of assessment in inquiry practices, and how these change following incorporation of assessment within an inquiry TEP.

Informed by the answers to phases 1 and 2 above,

3. How can PSTs be supported in the development of their knowledge and views of inquiry in an undergraduate chemistry laboratory module?

This thesis presents the findings from European inquiry and inquiry with assessment teacher education programmes. These results were used to inform the development and implementation of a chemistry module through inquiry based instruction for pre-service teachers.

The results from an intervention designed and implemented with a cohort of pre-service science teachers (PSTs) over a 12 week undergraduate chemistry laboratory in Ireland are presented here. The design of this intervention has been informed by literature on inquiry and assessment as well as effective teacher education. Guskey (2002) concluded that teachers need to trial a method and see the impact on students' learning and consequently change their attitudes and beliefs, and this has been a major influence on this study.

The first phase of this study focussed on determining the understanding of inquiry and views towards inquiry of European PSTs, and the changes in understanding that can be achieved through IBSE focussed PST professional development. The second phase of this study was to examine PSTs' understanding of inquiry and assessment in inquiry, and to determine the changes that can be achieved through inquiry and inquiry assessment professional development programmes. The lessons learned from these two phases allowed for the adoption of the approach so that the impact of an inquiry based approach to teaching, learning and assessment within a pre-service teachers' educational programme could be modelled and evaluated. The key findings are discussed with regard to the three phases of this study.

7.1. Changes in PSTs' understanding and views of inquiry practices following TEP

The first phase of this study determined PSTs' understanding and views of inquiry practices, and how these changed following an inquiry TEP. Data to measure the effect of focussed inquiry TEP on PSTs' understanding and views of inquiry was collected as part of the pan-European ESTABLISH project and is presented in Chapter 3.

Initial Understanding and Views of Inquiry

From the responses of the initial questionnaire carried out with 367 PSTs as part of the ESTABLISH project, the PSTs self-rated their experience with inquiry. The analysis described in Chapter 3 highlighted that PST across Europe expressed some understanding of inquiry, and in particular the role of the student in the inquiry classroom. Analysis shows that their understanding of inquiry is linked to their prior experience with inquiry. Those with some experience of inquiry have a significantly greater understanding than those who are beginners with inquiry. Although uncertain about whether inquiry will ever be their main teaching method, those that have a lower understanding of inquiry were more likely to indicate that it will never be their main approach to teaching. This suggests that increasing PST's experience and understanding of inquiry may lead to them considering inquiry as their main teaching method in future.

One of the major barriers to implementing inquiry that has been identified within literature is a lack of classroom time (Anderson, 2007). In terms of challenges identified by the European PSTs, a lack of time to implement inquiry and absence of assistance in school laboratories were the primary challenges identified by them. Results from Chapter 3 show that European PSTs are quite uncertain about whether inquiry takes up too much classroom time for them to implement. Half of the PSTs believe that inquiry is suitable for achieving the aims of the curriculum, and over half believe that it is suitable for students of varying capabilities. Importantly, those with more experience with inquiry agree with the suitability of inquiry more than those who have less experience with inquiry. The beginner group identified intrinsic challenges to implementing inquiry, such as limited knowledge of teaching by inquiry, more than those who have experience with inquiry.

Despite these views, PSTs do not feel that they have sufficient knowledge to implement an inquiry lesson effectively and they are uncomfortable teaching or asking questions where they are unsure of the answers themselves. An adequate grasp of content knowledge has previously been found to play a key role in whether or not novice teachers implement inquiry successfully. Without a good standard of content knowledge, novice teachers rely on textbooks (Roehrig & Luft, 2004). A focus on developing PSTs' content knowledge should be considered for future TEPs to address these issues. Additionally, their discomfort with asking higher order questions and questions where they do not know the answer suggests that they need to develop their own skills of encouraging thinking and reasoning strategies in the classroom.

PSTs agree that developing content knowledge is <u>not</u> more important than developing the thinking and reasoning processes of their students, despite many considering that their goal was to transfer factual knowledge to their students. Worryingly, an understanding that good teachers ask higher order questions is not universal among PSTs. There is a dichotomy between their views on thinking and reasoning processes and factual knowledge in the classroom. Further focus needs to be placed in future TEPs on the use of higher order questioning and reasoning processes.

Importantly, the PSTs are very open about changing their methodologies, even if they are happy with their current teaching methods. This indicates that it is beneficial for PSTs to experience different pedagogies when they are novice teachers and are open to trying various methods within their classrooms.

Changes in Understanding and Views of Inquiry

The final questionnaire that participants of the ESTABLISH project completed was obtained from 217 PSTs. Analysis of this data demonstrated that the PSTs' understanding of inquiry improved following the TEP. Developing PSTs' understanding of inquiry and the role of the students and teacher is achievable in a TEP such as the one outlined in Chapter 3, where the PSTs have the opportunity to experience the methodology for themselves in the role of the student.

Following the TEP, the PSTs are surer that inquiry is not only suitable for very capable students. The beginners' views towards the time it takes to implement inquiry changed, indicating they no longer believe it takes too much time.

The primary challenges that the PSTs identified (time to implement inquiry and absence of equipment or assistance) were unchanged by this TEP approach, indicating that further work needs to be carried out to identify strategies to help support teachers overcoming these barriers. After the TEP however, the beginners with inquiry identified challenges which were more in-line with those of who have some experience with inquiry. They no longer cite intrinsic challenges as a concern to the same extent as previously. Extrinsic challenges are now more of a barrier to them, such as a lack of a supportive school management and curriculum constraints.

Irish Sample

The Irish sample in this study started with and developed a similar understanding of inquiry to their European counterparts, so the approach which was used was suitable for developing understanding of inquiry. However, the Irish PSTs were more likely to believe that inquiry only suits very capable students.

Irish PSTs struggle with classrooms where students are carrying out different activities more than their European peers, and they are also more apprehensive about changing their current teaching methods. Irish PSTs need to be encouraged if they are to change to an alternative instructional method and supported during the development of their skills.

Irish PSTs tend to feel that good teachers focus on curriculum content only and that they should present facts and then explain them. Due to the more broad scope of many inquiry lessons, it would be useful if the PST were more open to moving beyond curriculum specific content and teaching in a way that isn't just only about presenting facts and explaining them.

7.2. Changes in PSTs' understanding and views of assessment in inquiry practices following TEP

The second phase of this study determined PSTs' understanding and views of assessment in inquiry practices, and how these changed following incorporation of assessment within an inquiry TEP. Data to measure the effect of focussed inquiry TEP on PSTs' understanding and views of inquiry and assessment of inquiry was collected as part of the pan-European SAILS project and is presented in Chapter 4.

Initial Understanding and Views of Inquiry and Assessment in Inquiry

269 PSTs participating in the SAILS project completed the initial questionnaire, where they indicated if they had prior teaching experience (PSTW) or not (PSTWO). Chapter 4 identified that PSTW have a greater understanding of inquiry than PSTWO, indicating that prior classroom experience may have allowed the PSTW to develop a greater understanding of what the methodology may look like. Interestingly, all of the PST groups have similar understandings of assessment of inquiry, irrespective of their prior classroom experience. This includes the Irish PSTs who hold similar understandings.

Their responses have indicated that the PSTs are not completely comfortable with students having control in the classroom. The focus of the PSTW's assessment appears to be on what is easier to assess. Often their assessment focuses on outcomes rather than processes, which are also of value. The practices that PSTW are carrying out are related to what they are assessing and what they are confident assessing. If their confidence is a barrier, then by developing the confidence of PSTW in assessing these practices, they may begin to carry out these practices more frequently in their classrooms. The majority of the PSTs are unconfident with assessing students formulating and refining questions which can be answered by investigations. It is clear that PST need support developing their skills at generating and supporting student questions which can be answered by investigations.

Overall the PSTs recognise the value of feedback on student learning. However, many are uncertain about the benefits of peer feedback, which may be due to the PSTs not being convinced that they can assess their own work, and the work of others, effectively (van Gennip, et al., 2010).

Changes in Understanding and Views of Inquiry and Assessment in Inquiry

An aspect that is not always a focus in inquiry TEP programmes is guidance on how to assess the outcomes of inquiry lessons. The SAILS partners incorporated inquiry assessment into their TEP. 175 PSTs completed the final questionnaire distributed following the SAILS TEP. Similar to results obtained in Chapter 3, following a TEP where the focus was on experiencing inquiry and inquiry assessment first hand, the PSTs developed a greater understanding of inquiry and assessment in inquiry. This is an approach which can be adapted for use within future PST modules.

The inquiry and assessment in inquiry TEP was successful at increasing the confidence of both the PSTW and PSTWO groups when assessing inquiry practices, meaning that the approach is equally suitable for those with and without prior teaching experience. However, the PSTWO are still more confident with assessing these practices. The PSTWO are more open than the PSTW to the possibilities of looking at a range of assessment opportunities.

After taking part in the TEP which included in-class feedback and peer assessment, both the PST groups agree more that quality feedback happens in the classroom during interactions with students and that peers are the best form of feedback.

Irish Sample

The Irish PSTs did not differ from the European sample in their understanding of inquiry and assessment of inquiry. The most assessed practices by the Irish PSTs were that each student has a role as investigations are conducted, that students develop their own conclusions, and understand why the data they collect is important. In terms of the confidence of Irish PSTs, they are most confident assessing that each student has a role as investigations are conducted, students are analysing their own data and that students develop their own conclusions.

The Irish PSTs were more positive about the benefits of feedback on students' learning and less likely to believe that quality feedback happens interactively and immediately in the classroom while students are learning.

After the TEP, the Irish PSTs showed significantly greater understanding of the nature of assessment in an inquiry classroom and expressed significantly more confidence assessing and providing feedback within an inquiry classroom.

7.3. Development and Evaluation of Undergraduate Chemistry module for PSTs.

Phase 3 of this study focussed on development and evaluation of an undergraduate chemistry module for PSTs to support the development of their knowledge of and views towards inquiry practices. Results from this phase could address the research question: "how can PST be supported in the development of their knowledge of and views towards inquiry in an undergraduate chemistry laboratory module?"

The design of the framework for this intervention is discussed in Chapter 5 and findings to show the effect of focussed inquiry TEP on participants' understanding and views of inquiry and assessment of inquiry is presented in chapter 6.

The participants taking part in this study were 34 PSTs taking part in inquiry labs. A predominantly inquiry approach was used throughout the 11 weeks so that the participants could experience the methodology first-hand as a learner, as they are unable to experience this within a classroom setting where they are the teacher.

This module improved the participants' understanding of chemistry, and the grades of the students appear to be maintained over the course of the module. The lower range of results is narrowing indicating less "low achievers" in chemistry overall. Evaluation of the participants planning investigations indicated that they had developed the skill over the course of the module, and they also demonstrated that they had developed the skill of critiquing experiments.

Over the duration of the module the participants began suggesting more inquiry-type activities in their teaching approach in comparison to their initial suggestions where ideas were generally chalk-and-talk, teacher led activities. Having studied chemistry in second level initially helped the PST in their comfort suggesting inquiry activities. However, towards the end of the module there are no distinctions between the approaches suggested based on level of subject experience. Previously, a relationship between scientific content knowledge and inquiry practices had been identified (Roehrig & Luft, 2004). This current study indicates that the more they experience inquiry, the less content knowledge impacts on how their teaching approach relates to inquiry.

The views of the participants on the “impact of teacher effort” or an “effective science teaching methodology” did not change following the module, indicating that they have strongly held views of these aspects and these remain unchanged.

Guskey (2002) advocates an approach where teachers need to trial a method and see the impact on students’ learning and consequently change their attitudes and beliefs. In this study a PST-suitable approach was developed where the participants experience inquiry and assessment as students and reflect on the impact on their own learning and development. Results show this module was successful in developing the confidence of participants, none of which had teaching experience. The participants are more comfortable with the idea of relinquishing some (teacher) control of learning in the classroom and allowing students to take more ownership. Their confidence with teaching through inquiry has increased over the course of the module. They are more confident teaching science in their classroom and they enjoy science more. Although it is impossible to say at this stage how the participants will actually go on to teach in their classrooms, this study shows positive indications for their future teaching.

This study shows that through a careful choice of methodology, activities, and assessments, PSTs’ views of and approach to science teaching can be influenced through a chemistry content laboratory module.

7.4 Limitations and Implications of this Study

Limitations of Study

This study involved the use of case study and quantitative approaches. These came with strengths and weaknesses.

One of the benefits of the case study approach is that it allows for focus on one group and analysis of various aspects of the cohort. However, a weakness of this approach is that since only one group was used the results are not generalizable. Another benefit of this approach is that it is practitioner based. Observations could be utilised from the researcher's journal to clarify aspects of the study. However, this means that the research is not conducted independently and the argument could be made that the researcher may see what they are choosing to see.

Another limitation of this study relates to the group selected for the final study. As a whole, the cohort does not have an interest in chemistry which may have impacted their engagement with certain aspects of the module. The participants had not been out on teaching practice before, so their understanding of how they will act in the classroom is limited. Additionally, due to the nature of their course, there were no opportunities to carry out follow up interviews or to obtain data after they had carried out teaching practice.

In terms of the quantitative approach taken in Chapters 3 and 4, one of the limitations was that the only data obtained came from participants of the ESTABLISH and SAILS workshops. It is not a fully representative sample of science teachers across Europe as some of the participants would have chosen to take part in these workshops. Additionally, the questionnaires were all self-reported information so items relating to their practices may not completely align with that they actually do. Finally, there was a lack of information available from the European projects on the detailed content of many of the teacher education programmes within this study.

Implications of Study

The focus of the work in this thesis is research influencing practice. Childs has previously noted that "*Despite several decades of research into the teaching and learning of Science/Chemistry, at both secondary and tertiary level, it has had relatively little impact on practice*" (2009, p. 189). This study incorporated the outputs of quantitative studies into the design and implementation of a module which was then evaluated using a case study. This study identified what is necessary for developing the understanding of and views towards inquiry with PSTs, and has shown how these aspects can be incorporated into teaching.

In terms of recommendations, this module has been shown to be successful with the particular cohort chosen. The researcher suggests determining if this module can be used with other PST groups, from different courses or from different subject backgrounds. It would also be interesting to determine if the approach could be applied in other discipline specific modules, such as physics.

As the views of the participants in the module relating to the impact of teacher effort or an effective science teaching methodology did not change following the module, a greater emphasis should be placed on the impact of different methodologies used over the course of the module when it is implemented again. This will highlight the impact of the approaches and the impact of teachers on students. As not all of the activities included in the module will be inquiry based, the PSTs could be asked to consider what the benefits of different methodologies are in different situations, or why a teacher would choose one option over the other.

Differences exist between PST with and without teaching experience, and this has been highlighted within the results of Chapter 4. The researcher suggests that a longitudinal study be carried out to track the attitudes and beliefs of PSTs who have taken part in a module such as this, during and after their teaching practice and into their teaching career, to determine any changes that occur when they have had the opportunity to trial the approach themselves. It would be valuable to determine what they incorporate into their own teaching from what they have experienced within the study. This is important as Guskey (2002) suggests teachers should be encouraged to address or try out their practices so they may see evidence of student learning which will ultimately change their attitudes and beliefs towards the pedagogy.

This study has shown that learning science through the methodology that we are trying to promote has been successful. This study suggests teaching PSTs new material through the targeted methodology to change their views and approach towards teaching. Integrating different approaches throughout the module was also successful and future programmes should consider this approach as PSTs then have an array of experiences with which to draw from.

In this study, the PSTs were scaffolded in the development of their skills. Early on in the module the participants were provided with a long term goal (the project proposal) that they were required to think through over the course of the module. Over the course of the module in their laboratory tasks and assessments, the participants developed the skills necessary to complete their task, such as planning investigations. This approach is recommended for the development of skills in future modules.

During this module the participants critiqued their own work and the work of their peers. They carried out this task both in the role of the student and in the role of the teacher. This is approach is recommended for future programmes as it prepares the PSTs so that they may be able to help their own students in future.

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Appendix A.1: ESTABLISH Initial questionnaire

PRESERVICE TEACHER QUESTIONNAIRE - A

This questionnaire examines inquiry based teaching as part of the ESTABLISH project.
Your participation is greatly appreciated.

Section A: Background Information

1. Name:____________________ **2. Age:** ________________________

3. Sex: Male ☐ Female ☐ **4. Year in University:** _________________

5. University/Institution: ____

6. Previous qualification(s):____

7. Previous Teaching Experience (Weeks spent teaching): _____________________________

8. Future Teaching Subject(s):
Integrated Science ☐ Chemistry ☐ Physics ☐ Biology ☐ Maths ☐

9. Future Teaching Level(s): lower second level ☐ upper second level ☐ both ☐

10. In your experience with inquiry based teaching do you consider yourself:

a. A complete beginner ☐
b. To have some experience ☐
c. Very experienced ☐

Section B. My Views of Inquiry

Please indicate your level of agreement with each of the following statements.

	Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree
11. I don't fully understand inquiry based science education.					
12. I don't fully understand my role as a teacher in an inquiry classroom.					
13. I don't fully understand the role of the students in an inquiry classroom.					
14. I think inquiry takes up too much classroom time for me to implement.					
15. The use of inquiry is appropriate to achieving the aims of the curriculum.					
16. Inquiry based teaching is only suitable for very capable students.					
17. Inquiry will never be my main teaching method.					

17. In your opinion, what are the benefits of inquiry based teaching?

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18. If you have used inquiry based teaching, what percentage of your teaching time did you spend using it?

____

____

19. Give an example of how you have used inquiry based teaching.

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Section C. Attitudes and views towards science and teaching science:

Please indicate your level of agreement with each of the following statements.

In my opinion,	Strongly Disagree	Disagree	Uncertai n	Agree	Strongly Agree
20. Scientific theories (e.g. atomic theory) are constant unchanging bodies of knowledge.					
21. Scientific knowledge is primarily focused on knowing facts					
In my opinion, when teaching science…	Strongly Disagree	Disagree	Uncertai n	Agree	Strongly Agree
22. Developing students' specific content knowledge is much more important than developing their thinking and reasoning processes.					
23. Teaching is more effective when all students are doing the same activity at the same time.					
24. It would be easy to teach the curriculum using inquiry based methods.					
25. Good teachers ask higher order questions.					
26. Good teachers focus on curriculum content only.					
27. Good teachers use student questions to guide their teaching.					
28. Good teachers present facts and then explain them.					
29. Good teachers allow students to develop their own investigation/research questions.					
30. Students need to know a lot of facts before they can participate in inquiry activities.					
31. My goal is to transfer factual knowledge to the students.					
32. Good teachers encourage student discussion on scientific topics relevant to everyday life.					
33. I am happy with my current teaching methods.					
34. I am open to trying different methodologies in my teaching.					
35. I feel apprehensive about changing my current teaching practice.					
36. I want my students to know about the latest developments and applications of science and engineering.					
37. I can easily relate scientific concepts in the curriculum to phenomena beyond the classroom.					
38. Good teachers show students the relevance of science in industry					
39. Good teachers help students understand the importance of science and technology for our society.					
40. If I had more information about industrial processes, I would use it in my teaching.					

Section D. Teaching science

Please indicate your level of agreement with each of the following statements.

	Strongly disagree	Disagree	Uncertain	Agree	Strongly agree
41. If a student investigation leads to an unexpected result I should always tell the students the right answer/ result.					
42. I would find it difficult to manage a classroom where each student group is doing different activities.					
43. I am unsure how to ask students higher order questions that promotes thinking.					
44. I have sufficient knowledge of science to implement an inquiry lesson effectively					
45. I am uncomfortable with teaching areas of science that I have limited knowledge of.					
46. If I don't know the answers to students questions I would feel inadequate as a teacher					
47. I would be uncomfortable with asking questions, in my class, where I am unsure of the answer myself.					

Section E: Challenges in Inquiry Teaching

48. Teachers may face a variety of challenges in implementing inquiry-based teaching. Please **rank** your TOP THREE challenges, as they apply to you, starting with 1 as your biggest concern:

Lack of time to implement inquiry	
Curriculum constraints	
Lack of equipment/assistance in school laboratories	
Lack of supportive school management	
Classroom management issues	
Limited scientific content knowledge to use inquiry effectively	
Limited knowledge of teaching by inquiry	
Assessment methods for inquiry	
Limited knowledge of ICT as used in inquiry	
Other (Please list):	
None of the above – I teach by inquiry	

Appendix A.2: ESTABLISH Final questionnaire

PRESERVICE TEACHER QUESTIONNAIRE - B

This questionnaire examines inquiry based teaching as part of the ESTABLISH project.

Your participation is greatly appreciated.

Section A: Background Information

1. Name:___________________________ **2. Year in University:_____**

3. University/Institution:____________________

4. Previous Teaching Experience (Weeks spent teaching): _________________

5. In your experience with inquiry based teaching do you consider yourself: (Tick appropriate box)

a. A complete beginner ☐
b. To have some experience ☐
c. Very experienced ☐

Section B. My Views of Inquiry

Please indicate the level of your agreement with each of the following statements.

	Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree
6. I don't fully understand inquiry-based science education					
7. I don't fully understand my role as a teacher in an inquiry classroom					
8. I don't fully understand the role of the students in an inquiry classroom					
9. I think inquiry takes up too much classroom time for me to implement.					
10. The use of inquiry is appropriate to achieving the aims of the curriculum.					
11. Inquiry-based teaching is only suitable for very capable students.					
12. Inquiry will never be my main teaching method					

13. In your opinion, what are the benefits of using inquiry based teaching?

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14. If you have used inquiry, what percentage of your teaching time did you spend using it?

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15. Outline what you did when using inquiry based teaching.

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16. Outline what your students did when at inquiry lessons.

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Section C. Industrial Content Knowledge and Authentic Experiences

Please indicate the level of your agreement with each of the following statements.

In my opinion, when teaching science,	Strongly disagree	Disagree	Uncertain	Agree	Strongly agree
17. I want my students to know about the latest developments and applications of science and engineering.					
18. I can easily relate scientific concepts in the curriculum to phenomena beyond the classroom.					
19. I often showed students the relevance of science in industry					
20. My students understood the importance of science and technology for our society.					
21. If I had more information about industrial processes, I would use it in my teaching.					

Section D. Teaching science

Please indicate the level of your agreement with each of the following statements.

	Strongly disagree	Disagree	Uncertain	Agree	Strongly agree
22. If a student investigation leads to an unexpected result I always tell the students the right answer/result.					
23. I find it difficult to manage a classroom where each student group is doing different activities.					
	Strongly disagree	Disagree	Uncertain	Agree	Strongly agree
24. I am unsure how to ask students higher order questions that promotes thinking.					
25. I have sufficient knowledge of science to implement an inquiry lesson effectively					
26. I am uncomfortable with teaching areas of science that I have limited knowledge of.					
27. If I don’t know the answers to students questions I feel inadequate as a teacher					
28. I am uncomfortable with asking questions, in my class, where I am unsure of the answer myself.					

Section E: Challenges in Inquiry Teaching

29. Teachers may face a variety of challenges in implementing inquiry-based teaching. Please **rank** your TOP THREE challenges, as they apply to you, starting with 1 as your biggest concern:

Lack of time to implement inquiry	
Curriculum constraints	
Lack of equipment/assistance in school laboratories	
Lack of supportive school management	
Classroom management issues	
Limited scientific content knowledge to use inquiry effectively	
Limited knowledge of teaching by inquiry	
Assessment methods for inquiry	
Limited knowledge of ICT as used in inquiry	
Other (Please list):	
None of the above – I teach by inquiry	

Appendix A.3: SAILS In-Service Teacher Questionnaire – Initial questionnaire

Section A: Background Information

1. Name: ____

2. Sex: Male ☐ Female ☐

3. School: ____

4. Type of school: All boys ☐ All girls ☐ Mixed ☐

5. Years of Teaching Experience: < 5 years ☐ 5-10 years ☐ 11-20 years ☐ > 20 years ☐

6. Teaching Subject(s): Integrated Science ☐ Chemistry ☐ Physics ☐ Biology ☐ Maths ☐ Other ☐ If other, please explain:

____

7. Age of your students: (multiple answers possible)

≤14 years ☐ 15-16 years ☐ >16 years ☐

8. Total number of different students you teach in a week:

< 100 ☐ 100-150 ☐ 151-200 ☐ > 200 ☐

9. In your experience with inquiry based teaching, do you consider yourself to have: (Tick appropriate box)

a. no / hardly any knowledge about IBSE ☐
b. some knowledge about IBSE but no practical experience with IBSE in class ☐
c. some/limited experience with IBSE in class ☐
d. good knowledge of and regularly use IBSE in class ☐

Section B: IBSE & Assessment - Please circle one number for each statement

	Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree
10. I have a comprehensive understanding of inquiry-based science education	1	2	3	4	5
11. I have a comprehensive understanding of my role as a teacher in an inquiry classroom	1	2	3	4	5
12. I have a comprehensive understanding of the role of the students in an inquiry classroom	1	2	3	4	5
13. I am confident using multiple assessment methods	1	2	3	4	5
14. I have a comprehensive understanding of the nature of assessment in an inquiry classroom	1	2	3	4	5
15. In an inquiry classroom I can easily highlight strengths and weaknesses of a particular student's work	1	2	3	4	5

Section C: Inquiry Processes **-** Please circle one number in each box.

Strongly disagree → Strongly Agree **1 → 5**	**In my classroom, this practice almost always occurs**	**Do you currently assess this?** **Yes/ No**	**I am confident in assessing this practice**
16. Students formulate questions which can be answered by investigation*	**1 2 3 4 5**	**Y N**	**1 2 3 4 5**
17. Time is devoted to refining student questions so that they can be answered by investigations*	**1 2 3 4 5**	**Y N**	**1 2 3 4 5**
18. Students design their own procedures for investigations. *	**1 2 3 4 5**	**Y N**	**1 2 3 4 5**
19. Students engage in critiquing the procedures that are used when they conduct investigations. *	**1 2 3 4 5**	**Y N**	**1 2 3 4 5**
20. Students conduct their own procedures of an investigation. *	**1 2 3 4 5**	**Y N**	**1 2 3 4 5**
21. Each student has a role as investigations are conducted*	**1 2 3 4 5**	**Y N**	**1 2 3 4 5**
22. When conducting an investigation, students determine which data to collect*	**1 2 3 4 5**	**Y N**	**1 2 3 4 5**
23. When conducting an investigation, students understand why the data they are collecting is important. *	**1 2 3 4 5**	**Y N**	**1 2 3 4 5**
24. Students analyse their own data.	**1 2 3 4 5**	**Y N**	**1 2 3 4 5**
25. Students develop their own conclusions for investigations.*	**1 2 3 4 5**	**Y N**	**1 2 3 4 5**
26. Students consider a variety of ways of interpreting evidence when making conclusions. *	**1 2 3 4 5**	**Y N**	**1 2 3 4 5**
27. Students justify their conclusions.*	**1 2 3 4 5**	**Y N**	**1 2 3 4 5**
28. Students present their results and conclusions from an investigation.	**1 2 3 4 5**	**Y N**	**1 2 3 4 5**
29. Students critique information from other sources, e.g. newspapers, web links, magazines	**1 2 3 4 5**	**Y N**	**1 2 3 4 5**
30. Students have opportunities to talk and listen to each other, in the inquiry classroom.	**1 2 3 4 5**	**Y N**	**1 2 3 4 5**
31. Students have opportunities to develop empathy with peers, in the inquiry classroom.	**1 2 3 4 5**	**Y N**	**1 2 3 4 5**
32. Students have the opportunity to respect and understand each other in the inquiry classroom.	**1 2 3 4 5**	**Y N**	**1 2 3 4 5**

* Questions 16 – 23, 25 – 27 adapted from Principles of Scientific Inquiry – Teacher (PSI-T) by Campbell *et al* (2010)

Section D: Feedback practices

Q33. When I assess inquiry, I give feedback to my students by: (Please circle one number for each statement)

Forms of feedback	Almost never	Seldom	Some-times	Often	Almost always
Writing grades on their written work	1	2	3	4	5
Writing comments on their written work	1	2	3	4	5
Writing questions on their written work	1	2	3	4	5
Writing comments, highlighting correct work and areas for further learning	1	2	3	4	5
Discussing examples of student work with the class	1	2	3	4	5
Discussing quality of inquiry with students	1	2	3	4	5
Negotiating next steps in learning	1	2	3	4	5

	Almost never	Seldom	Sometimes	Often	Almost always
34. I suggest improvements to my students during inquiry activities	1	2	3	4	5
35. I give students opportunities to respond to my feedback	1	2	3	4	5
36. Students use comments I give them to revise their inquiry activity	1	2	3	4	5
37. I organise time in class for students to peer assess	1	2	3	4	5
38. Students use feedback I give them to improve their inquiry skills	1	2	3	4	5
39. I assess the teamwork skills of individuals during group work	1	2	3	4	5

40. What records do you keep of the feedback given to students?

Grades only ☐ Grades and comments ☐ Comments only ☐ No records ☐

If you have any other comments on inquiry or assessment, please expand here.

Appendix A.4: SAILS In-Service Teacher Questionnaire – Final questionnaire

Section A: Background Information

1. Name: ______________________________________ **2. Sex:** Male ☐ Female ☐

3. In your experience with inquiry based teaching do you consider yourself to have: (Tick appropriate box)

a. no / hardly any knowledge about IBSE ☐
b. some knowledge about it but no practical experience with IBSE in class ☐
c. some/limited experience with IBSE in class ☐
d. good knowledge and regular use of IBSE in class ☐

Section B: IBSE & Assessment - Please circle one number for each statement

	Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree
4. I have a comprehensive understanding of inquiry-based science education	1	2	3	4	5
5. I have a comprehensive understanding of my role as a teacher in an inquiry classroom	1	2	3	4	5
6. I have a comprehensive understanding of the role of the students in an inquiry classroom	1	2	3	4	5
7. I am confident using multiple assessment methods	1	2	3	4	5
8. I have a comprehensive understanding of the nature of assessment in an inquiry classroom	1	2	3	4	5
9. In an inquiry classroom I can easily highlight strengths and weaknesses of a particular student's work	1	2	3	4	5

Section C: Feedback practices - Please circle one number for each statement

	Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree
10. The nature of my feedback has changed following Teacher Education Programme	1	2	3	4	5
11. I organise time in class for students to revise, evaluate, and give themselves feedback about their own individual work	1	2	3	4	5
12. I give students opportunities to respond to my feedback	1	2	3	4	5
13. I give feedback immediately after they finish	1	2	3	4	5
14. Students use comments I give them to revise their work	1	2	3	4	5
15. Students use feedback I give them to improve their work	1	2	3	4	5

Section D: Inquiry Processes Following Your Teacher Education Programme -

Please circle one number in each box.

Strongly disagree → Strongly Agree **1 →5**	**Do you think assessing this practice is valuable**	**I am confident in assessing this practice**
16. Students formulate questions which can be answered by investigation*	**1 2 3 4 5**	**1 2 3 4 5**
17. Time is devoted to refining student questions so that they can be answered by investigations*	**1 2 3 4 5**	**1 2 3 4 5**
18. Students design their own procedures for investigations. *	**1 2 3 4 5**	**1 2 3 4 5**
19. Students engage in critiquing the procedures that are used when they conduct investigations. *	**1 2 3 4 5**	**1 2 3 4 5**
20. Students conduct their own procedures of an investigation. *	**1 2 3 4 5**	**1 2 3 4 5**
21. Each student has a role as investigations are conducted*	**1 2 3 4 5**	**1 2 3 4 5**
22. When conducting an investigation, students determine which data to collect*	**1 2 3 4 5**	**1 2 3 4 5**
23. When conducting an investigation, students understand why the data they are collecting is important. *	**1 2 3 4 5**	**1 2 3 4 5**
24. Students analyse their own data.	**1 2 3 4 5**	**1 2 3 4 5**
25. Students develop their own conclusions for investigations.*	**1 2 3 4 5**	**1 2 3 4 5**
26. Students consider a variety of ways of interpreting evidence when making conclusions. *	**1 2 3 4 5**	**1 2 3 4 5**
27. Students justify their conclusions.*	**1 2 3 4 5**	**1 2 3 4 5**
28. Students present their results and conclusions from an investigation.	**1 2 3 4 5**	**1 2 3 4 5**
29. Students critique information from other sources, e.g. newspapers, web links, magazines	**1 2 3 4 5**	**1 2 3 4 5**
30. Students have opportunities to talk and listen to each other, in the inquiry classroom.	**1 2 3 4 5**	**1 2 3 4 5**
31. Students have opportunities to develop empathy with peers, in the inquiry classroom.	**1 2 3 4 5**	**1 2 3 4 5**
32. Students have the opportunity to respect and understand each other in the inquiry classroom.	**1 2 3 4 5**	**1 2 3 4 5**

* Questions 16 – 23, 25 – 27 adapted from Principles of Scientific Inquiry – Teacher (PSI-T) by Campbell *et al* (2010)

33. Teachers may face a variety of challenges in implementing assessment strategies for elements of inquiry. Please rank your TOP FOUR challenges (1,2,3,4), starting with 1 as your highest concern:

Preparation for National assessments	
In-school assessment policy	
Curriculum requirements	
Time required to develop assessment	
Time required to implement assessment	
Time required to grade assessment	
Lack of sample tests	
Lack of experience with alternative assessment practices	
Difficulty in developing scoring rubrics	
Resistance from students	
Resistance from parents	
Resistance from colleagues	
Other, please describe:	

If you have any other comments on inquiry or assessment, please expand here.

Appendix A.5: Pre-Service Questionnaire – Initial & Final

Section A: Background Information

1. Name: ___________________________________ **2. Sex:** Male ☐ Female ☐

3. University/ Institution: _____________________________ **4. Year in University: ______**

5. Previous Teaching Experience (Weeks spent teaching): _____________________

6. In your experience with inquiry based teaching do you consider yourself: (Tick appropriate box)

d. I have no / hardly any knowledge about IBSE ☐

e. I have some knowledge about it but no practical experience with IBSE in class ☐

f. I have some/limited experience with IBSE in class ☐

g. I have good knowledge and regular use of IBSE in class ☐

Section B: Indicate your level of agreement with the following statements - Please circle one number for each statement

IBSE & Assessment	**Strongly Disagree**	**Disagree**	**Uncertain**	**Agree**	**Strongly Agree**
1. I have a comprehensive understanding of inquiry-based science education	1	2	3	4	5
2. I have a comprehensive understanding of my role as a teacher in an inquiry classroom	1	2	3	4	5
3. I have a comprehensive understanding of the role of the students in an inquiry classroom	1	2	3	4	5
4. I am confident using multiple assessment methods	1	2	3	4	5
5. I have a comprehensive understanding of the nature of assessment in an inquiry classroom	1	2	3	4	5
6. In an inquiry classroom I can easily highlight strengths and weaknesses of a particular student's work	1	2	3	4	5
Feedback practices					
7. Giving students feedback is important because it helps them to learn	1	2	3	4	5
8. Feedback helps students decide what to include and/or exclude in their work	1	2	3	4	5
9. Time spent giving feedback is a wasted effort	1	2	3	4	5
10. The point of feedback is to make students feel good about themselves	1	2	3	4	5
11. Quality feedback happens interactively and immediately in the classroom while students are learning	1	2	3	4	5
12. Feedback that takes more than a week is useless	1	2	3	4	5
13. Feedback is about helping students evaluate their own work	1	2	3	4	5
14. Peers are the best source of feedback	1	2	3	4	5
15. Feedback is a two-way process between the students and the teacher	1	2	3	4	5

If you have classroom teaching experience, please complete Section C below.

If you do NOT have classroom experience, please complete Section D instead.

<u>Section C: Inquiry Processes – Please complete if you HAVE TEACHING EXPERIENCE</u>

- Please circle one number for each box.

Strongly disagree → Strongly Agree **1 →5**	**In my classroom, this practice almost always occurs**	**Do you currently assess this?** **Yes/ No**	**I am confident in assessing this practice**
16. Students formulate questions which can be answered by investigation*	1 2 3 4 5	Y N	1 2 3 4 5
17. Time is devoted to refining student questions so that they can be answered by investigations.*	1 2 3 4 5	Y N	1 2 3 4 5
18. Students design their own procedures for investigations. *	1 2 3 4 5	Y N	1 2 3 4 5
19. Students engage in critiquing the procedures that are used when they conduct investigations. *	1 2 3 4 5	Y N	1 2 3 4 5
20. Students conduct their own procedures of an investigation. *	1 2 3 4 5	Y N	1 2 3 4 5
21. Each student has a role as investigations are conducted *	1 2 3 4 5	Y N	1 2 3 4 5
22. When conducting an investigation, students determine which data to collect.*	1 2 3 4 5	Y N	1 2 3 4 5
23. When conducting an investigation, students understand why the data they are collecting is important.*	1 2 3 4 5	Y N	1 2 3 4 5
24. Students analyse their own data.	1 2 3 4 5	Y N	1 2 3 4 5
25. Students develop their own conclusions for investigations.*	1 2 3 4 5	Y N	1 2 3 4 5
26. Students consider a variety of ways of interpreting evidence when making conclusions. *	1 2 3 4 5	Y N	1 2 3 4 5
27. Students justify their conclusions. *	1 2 3 4 5	Y N	1 2 3 4 5
28. Students present their results and conclusions from an investigation.	1 2 3 4 5	Y N	1 2 3 4 5
29. Students critique information from other sources, e.g. newspapers, web links, magazines	1 2 3 4 5	Y N	1 2 3 4 5
30. Students have opportunities to talk and listen to each other, in the inquiry classroom.	1 2 3 4 5	Y N	1 2 3 4 5
31. Students have opportunities to develop empathy with peers, in the inquiry classroom.	1 2 3 4 5	Y N	1 2 3 4 5
32. Students have the opportunity to respect and understand each other in the inquiry classroom	1 2 3 4 5	Y N	1 2 3 4 5

Section D: ***Inquiry Processes –Please complete if you DO NOT HAVE TEACHING EXPERIENCE*** - Please circle one number for each box.

Strongly disagree → Strongly Agree **1 →5**	**I think that this practice is very important in the classroom**	**Do you want to assess this practice in future? Yes/No**	**I am confident that I can assess this practice**
16. Students formulate questions which can be answered by investigation*	**1 2 3 4 5**	**Y N**	**1 2 3 4 5**
17. Time is devoted to refining student questions so that they can be answered by investigations.*	**1 2 3 4 5**	**Y N**	**1 2 3 4 5**
18. Students design their own procedures for investigations. *	**1 2 3 4 5**	**Y N**	**1 2 3 4 5**
19. Students engage in critiquing the procedures that are used when they conduct investigations. *	**1 2 3 4 5**	**Y N**	**1 2 3 4 5**
20. Students conduct their own procedures of an investigation. *	**1 2 3 4 5**	**Y N**	**1 2 3 4 5**
21. Each student has a role as investigations are conducted *	**1 2 3 4 5**	**Y N**	**1 2 3 4 5**
22. When conducting an investigation, students determine which data to collect.*	**1 2 3 4 5**	**Y N**	**1 2 3 4 5**
23. When conducting an investigation, students understand why the data they are collecting is important.*	**1 2 3 4 5**	**Y N**	**1 2 3 4 5**
24. Students analyse their own data.	**1 2 3 4 5**	**Y N**	**1 2 3 4 5**
25. Students develop their own conclusions for investigations.*	**1 2 3 4 5**	**Y N**	**1 2 3 4 5**
26. Students consider a variety of ways of interpreting evidence when making conclusions. *	**1 2 3 4 5**	**Y N**	**1 2 3 4 5**
27. Students justify their conclusions. *	**1 2 3 4 5**	**Y N**	**1 2 3 4 5**
28. Students present their results and conclusions from an investigation.	**1 2 3 4 5**	**Y N**	**1 2 3 4 5**
29. Students critique information from other sources, e.g. newspapers, web links, magazines	**1 2 3 4 5**	**Y N**	**1 2 3 4 5**
30. Students have opportunities to talk and listen to each other, in the inquiry classroom.	**1 2 3 4 5**	**Y N**	**1 2 3 4 5**
31. Students have opportunities to develop empathy with peers, in the inquiry classroom.	**1 2 3 4 5**	**Y N**	**1 2 3 4 5**
32. Students have the opportunity to respect and understand each other in the inquiry classroom	**1 2 3 4 5**	**Y N**	**1 2 3 4 5**

* Questions 16-23, 25-27 adapted from Principles of Scientific Inquiry – Teacher (PSI-T) by Campbell, *et al* (2010)

Questions 7-15 adapted from Teacher Beliefs about Feedback within an Assessment Learning Environment Brown, et al., (2012)

Appendix A.6: Case Study PST Questionnaire

Background information:

Name: _______________ Age: _______________ Gender: _________

Year in University: _________________ Prior teaching experience (weeks): ______

What science subjects did you do for your Leaving Certificate?

____

Please tick one box for each item indicating your level of agreement with each statement.

		Strongly disagree	Disagree	Uncertain	Agree	Strongly agree
1.	When a student does better than usual in science, it is usually because the teacher exerted a little extra effort					
2.	The inadequacy of a student's science background can be overcome by good teaching					
3.	Given the opportunity, I think that I will be at ease having students take more ownership over what direction we take in our science investigations					
4.	I feel confident to teach science in my classroom					
5.	You have to be smart to be good at science					
6.	I think that I will find it difficult to explain to students why their science investigation did not work					
7.	I think that I will feel comfortable allowing students to develop their own science investigation research questions					
8.	Even if I try hard, I don't think I will be able to support students in developing their own research questions very well					
9.	I think that I will not be very effective monitoring science investigations					
10.	I understand the scientific research process well enough to be very effective in supporting student research investigations.					
11.	Even teachers with good science teaching abilities cannot help some kids learn science					
12.	I think that I will feel best when students conduct structured laboratory experiments					
13.	I think that I will feel comfortable giving students a problem to focus on and allowing them to come up with their own methods of investigation and analysis					
14.	I think that I will feel best when I have complete control of all of the student activities in the classroom					
15.	When supporting student research investigations, I think that I will welcome student questions					
16.	I don't think that I will know what to do to help students develop their own science research investigations					
17.	I think that I will feel very comfortable guiding students, listening to their questions, and supporting their investigations					

		Strongly disagree	Disagree	Uncertain	Agree	Strongly agree
18.	I feel confident in my ability to do science					
19.	I think that I will be at ease allowing my students to develop their own explanations for their findings					
20.	Keeping students on task will be my highest priority in the classroom					
21.	I enjoy science					
22.	When the science grades of students improve, it is most often due to their teacher having found a more effective teaching approach					
23.	If students are underachieving in science, it is most likely due to ineffective science teaching					
24.	I usually do well in science courses					
25.	The low science achievement of some students cannot generally be blamed on their teachers					
26.	I don't understand science at all					
27.	Increased effort in science teaching produces little change in some students' science achievement					
28.	The teacher is generally responsible for the achievement of students in science					
29.	Students' achievement in science is directly related to their teacher's effectiveness in science teaching					
30.	I think that I will have the skills to allow students design and conduct their own investigations					
31.	Effectiveness in science teaching has little influence on the achievement of students with low motivation					
32.	When a low achieving child progresses in science, it is usually due to extra attention given by the teacher					
33.	Scientific theories develop and change over time					
34.	School science has made me more critical and sceptical					
35.	School science has taught me how to take better care of my health					

Appendix B: Additional Tables and Figures – Chapter 3

Table B.1: Kruskal-Wallis H test results for Understanding of Inquiry

Statement	$\chi^2(2)$	P	Mean rank beg.	Mean rank some exp.
11. I don't fully understand inquiry based science education	8.656	.003	178.86	148.55
12. I don't fully understand my role as a teacher in an inquiry classroom	9.082	.003	178.95	148.13
13. I don't fully understand the role of the students in an inquiry classroom	4.999	.025	176.61	153.91

Table B.2: Significant changes in whole group understanding of inquiry

Statement	Z	p
11. I don't fully understand inquiry based science education	-3.906	.000
12. I don't fully understand the role of the students in an inquiry classroom	-4.344	.000
13. I don't fully understand the role of the students in an inquiry classroom	-3.295	.001

Table B.3: Kruskal-Wallis H test for views towards inquiry

Statement	$\chi^2(2)$	p	Mean rank beg.	Mean rank some exp.
15. The use of inquiry is appropriate to achieving the aims of the curriculum	4.842	.028	155.67	177.87
25. It would be easy to teach the curriculum using inquiry based methods	6.673	.010	154.25	180.48

Table B.4: Kruskal-Wallis H test for self-efficacy

Statement	$\chi^2(2)$	P	Mean rank beg.	Mean rank some exp.
46. I am uncomfortable with teaching areas of science that I have limited knowledge of	4.208	.040	173.15	152.93

Table B.5: Significant difference based on experience level

Statement	$\chi^2(2)$	p	Mean rank beg.	Mean rank some exp.
35. I am open to trying different methodologies in my teaching	4.709	.030	154.52	175.34

Table B.6: Responses in terms of content knowledge versus thinking and reasoning

	Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree
22. Scientific knowledge is primarily focused on knowing facts	8.4%	28.9%	13.9%	33.8%	5.7%
23. Developing students' specific content knowledge is much more important than developing their thinking and reasoning processes	28.3%	52.3%	7.1%	8.7%	0.8%
32. My goal is to transfer factual knowledge to the students	9.8%	27.2%	19.1%	30.5%	4.1%

Table B.7: Significant difference between experience levels for good teachers' content

Statement	$\chi^2(2)$	p	Mean rank beg.	Mean rank some exp.
27. Good teachers focus on curriculum content only	5.788	.016	155.57	179.34

Table B.8: Significant difference between experience levels and science outside the classroom

Statement	$\chi^2(2)$	p	Mean rank beg.	Mean rank some exp.
41. If I had more information about industrial processes, I would use it in my teaching	7.767	.005	152.45	181.02

Table B.9: Significant differences between Ireland and Europe for Views towards inquiry

Statement	$\chi^2(2)$	p	Mean rank – Ireland	Mean rank - Other
16. Inquiry based teaching is only suitable for very capable students	14.680	.000	216.57	167.84
31. Students need to know a lot of facts before they can participate in inquiry activities	7.928	.005	148.70	184.25

Table B.10: Significant differences between Ireland and Europe for self-efficacy

Statement	$\chi^2(2)$	p	Mean rank – Ireland	Mean rank - Other
43. I would find it difficult to manage a classroom where each student group is doing different activities	6.013	.014	195.92	165.42
44. I am unsure how to ask students higher order questions that promotes thinking	8.534	.003	149.51	184.83
46. I am uncomfortable with teaching areas of science that I have limited knowledge of	4.310	.038	151.10	174.12

Table B.11: Significant differences between Ireland and Europe for self-efficacy

Statement	$\chi^2(2)$	p	Mean rank – Ireland	Mean rank - Other
36. I feel apprehensive about changing my current teaching practice	7.069	.008	146.61	121.14

Table B.12: Significant differences between Ireland and Europe for good teaching

Statement	$\chi^2(2)$	p	Mean rank – Ireland	Mean rank - Other
26. Good teachers ask higher order questions	12.441	.000	212.21	167.32
27. Good teachers focus on curriculum content only	20.088	.000	222.34	167.19
29. Good teachers present facts and then explain them	11.713	.001	214.37	169.91
39. Good teachers show students the relevance of science in industry	5.514	.019	186.78	160.02

Table B.13: Significant differences between Ireland and Europe for Views of science

Statement	$\chi^2(2)$	p	Mean rank – Ireland	Mean rank - Other
22. Scientific knowledge is primarily focused on knowing facts	20.981	.000	123.84	179.33

Table B.14: Significant differences between Ireland and Europe for science outside the classroom

Statement	$\chi^2(2)$	p	Mean rank - Ireland	Mean rank - Other
37. I want my students to know about the latest developments and applications of science and engineering	4.868	.027	184.28	159.40
38. I can easily relate scientific concepts in the curriculum to phenomena beyond the classroom	6.557	.010	192.29	161.78
41. If I had more information about industrial processes, I would use it in my teaching	13.094	.000	198.16	155.38

Table B.15: Irish changes following the teacher education programme

Statement	Z	P
17. Inquiry will never be my main teaching method	-2.751	.006
37. I want my students to know about the latest developments and applications of science and engineering	-2.357	.022
38. I can easily relate scientific concepts in the curriculum to phenomena beyond the classroom	-2.311	.018

Appendix C: Additional Tables and Figures – Chapter 4

Table C.1: PSTW responses 1 – 15 initially

	Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree
1. I have a comprehensive understanding of inquiry-based science education	7.9%	25.0%	31.6%	30.9%	4.6%
2. I have a comprehensive understanding of my role as a teacher in an inquiry classroom	5.9%	14.5%	28.9%	42.1%	8.6%
3. I have a comprehensive understanding of the role of the students in an inquiry classroom	5.3%	13.8%	24.3%	49.3%	5.9%
4. I am confident using multiple assessment methods	4.6%	17.1%	32.9%	39.5%	4.6%
5. I have a comprehensive understanding of the nature of assessment in an inquiry classroom	12.5%	24.3%	36.8%	23.7%	2.0%
6. In an inquiry classroom I can easily highlight strengths and weaknesses of a particular student's work	7.9%	15.1%	37.5%	35.5%	3.9%
7. Giving students feedback is important because it helps them to learn	0.0%	0.7%	2.6%	34.2%	62.5%
8. Feedback helps students decide what to include and/or exclude in their work	0.7%	0.7%	15.8%	46.7%	35.5%
9. Time spent giving feedback is a wasted effort	55.9%	28.9%	5.9%	6.6%	2.0%
10. The point of feedback is to make students feel good about themselves	6.6%	30.3%	32.2%	27.0%	3.3%
11. Quality feedback happens interactively and immediately in the classroom while students are learning	0.7%	7.9%	35.5%	44.7%	11.2%
12. Feedback that takes more than a week is useless	7.2%	30.9%	40.8%	15.8%	5.3%
13. Feedback is about helping students evaluate their own work	0.7%	3.3%	11.2%	58.6%	26.3%
14. Peers are the best source of feedback	2.0%	21.1%	53.3%	18.4%	3.3%
15. Feedback is a two-way process between the students and the teacher	0.7%	3.3%	12.5%	56.6%	26.3%

Table C.2: PSTW responses for inquiry practices initially

	In my classroom, this practice almost always occurs (A)					Do you currently assess this? (B)		I am confident in assessing this practice (C)				
	SD	D	U	A	SA	Yes	No	SD	D	U	A	SA
16. Students formulate questions which can be answered by Investigation	2.6%	16.4%	39.5%	32.9%	7.2%	46.7%	50.7%	11.2%	26.3%	30.9%	21.7%	7.9%
17. Time is devoted to refining student questions so that they can be answered by investigations.	6.6%	19.7%	28.9%	35.5%	7.9%	34.9%	62.5%	20.4%	19.7%	31.6%	18.4%	7.2%
18. Students design their own procedures for investigations.	9.9%	30.9%	25.7%	27.0%	5.9%	42.1%	55.9%	15.1%	21.7%	32.2%	21.1%	7.9%
19. Students engage in critiquing the procedures that are used when they conduct investigations.	11.8 %	24.3%	23.7%	31.6%	7.2%	44.7%	52.6%	17.1%	23.7%	28.3%	21.1%	6.6%
20. Students conduct their own procedures of an investigation.	14.5 %	27.6%	28.9%	21.7%	5.9%	44.1%	53.9%	16.4%	23.7%	31.6%	21.7%	3.9%
21. Each student has a role as investigations are conducted	6.6%	18.4%	16.4%	40.1%	17.8%	54.6%	44.1%	13.2%	16.4%	27.6%	30.9%	9.2%
22. When conducting an investigation, students determine which data to collect.	14.5 %	26.3%	29.6%	21.7%	5.3%	36.2%	59.9%	19.1%	20.4%	33.6%	18.4%	5.3%
23. When conducting an investigation, students understand why the data they are collecting is important.	3.9%	12.5%	30.9%	40.1%	11.2%	57.9%	40.8%	9.9%	16.4%	34.9%	28.3%	7.9%
24. Students analyse their own data.	2.0%	13.8%	23.7%	46.1%	13.8%	65.1%	33.6%	7.2%	15.8%	27.6%	38.2%	9.2%
25. Students develop their own conclusions for investigations.	2.6%	10.5%	19.7%	45.4%	21.1%	67.8%	31.6%	5.3%	10.5%	35.5%	32.9%	13.8%
26. Students consider a variety of ways of interpreting evidence when making conclusions.	8.6%	21.1%	35.5%	27.6%	5.9%	42.8%	56.6%	13.8%	22.4%	34.9%	21.7%	5.9%
27. Students justify their conclusions.	3.9%	9.2%	25.0%	42.8%	17.8%	67.1%	31.6%	5.9%	14.5%	28.9%	35.5%	13.8%
28. Students present their results and conclusions from an investigation.	5.3%	9.2%	17.8%	42.1%	24.3%	63.2%	35.5%	8.6%	12.5%	27.0%	29.6%	19.7%
29. Students critique information from other sources, e.g. newspapers, web links, magazines	16.4 %	27.6%	23.0%	21.7%	9.9%	37.5%	61.8%	21.1%	14.5%	31.6%	20.4%	9.9%
30. Students have opportunities to talk and listen to each other, in the inquiry classroom.	7.2%	5.9%	20.4%	42.1%	22.4%	54.6%	44.1%	12.5%	11.8%	30.9%	27.0%	14.5%
31. Students have opportunities to develop empathy with peers, in the inquiry classroom.	8.6%	8.6%	28.9%	36.2%	15.8%	34.2%	63.8%	24.3%	10.5%	33.6%	21.1%	7.9%
32. Students have the opportunity to respect and understand each other in the inquiry classroom	5.3%	3.9%	21.7%	44.7%	22.4%	46.1%	51.3%	16.4%	10.5%	25.0%	30.9%	13.8%

*Where SD, D, U, A, SA correspond to Strongly disagree, Disagree, Uncertain, Agree, Strongly agree, respectively.

Table C.3: PSTWO responses 1 – 15 initially

	Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree
4. I have a comprehensive understanding of inquiry-based science education	13.7%	25.6%	36.8%	18.8%	3.4%
5. I have a comprehensive understanding of my role as a teacher in an inquiry classroom	1.7%	16.2%	41.9%	30.8%	6.0%
6. I have a comprehensive understanding of the role of the students in an inquiry classroom	2.6%	12.0%	45.3%	30.8%	6.8%
7. I am confident using multiple assessment methods	2.6%	23.9%	39.3%	23.1%	6.8%
8. I have a comprehensive understanding of the nature of assessment in an inquiry classroom	6.8%	20.5%	53.8%	12.0%	4.3%
9. In an inquiry classroom I can easily highlight strengths and weaknesses of a particular student's work	7.7%	13.7%	28.2%	38.5%	6.8%
16. Giving students feedback is important because it helps them to learn	0.9%	0.9%	7.7%	40.2%	47.9%
17. Feedback helps students decide what to include and/or exclude in their work	0.9%	3.4%	16.2%	47.0%	29.9%
18. Time spent giving feedback is a wasted effort	41.9%	42.7%	11.1%	0.9%	0.0%
19. The point of feedback is to make students feel good about themselves	0.9%	11.1%	39.3%	35.9%	9.4%
20. Quality feedback happens interactively and immediately in the classroom while students are learning	0.0%	4.3%	29.9%	53.0%	10.3%
21. Feedback that takes more than a week is useless	3.4%	27.4%	39.3%	17.9%	8.5%
22. Feedback is about helping students evaluate their own work	0.0%	0.9%	19.7%	52.1%	24.8%
23. Peers are the best source of feedback	2.6%	23.1%	47.9%	18.8%	2.6%
24. Feedback is a two-way process between the students and the teacher	0.0%	0.9%	23.9%	48.7%	23.9%

Table C.4: PSTWO responses for inquiry practices initially

	I think that this practice is very important in the classroom (A)					Do you want to assess this practice in future? (B)		I am confident that I can assess this practice (C)				
	SD	D	U	A	SA	Yes	No	SD	D	U	A	SA
16. Students formulate questions which can be answered by Investigation	0.9%	0.9%	9.4%	45.3%	43.6%	86.3%	13.7%	3.4%	7.7%	41.9%	35.0%	10.3%
17. Time is devoted to refining student questions so that they can be answered by investigations.	0.9%	4.3%	21.4%	37.6%	35.9%	76.1%	21.4%	3.4%	10.3 %	38.5%	30.8%	16.2%
18. Students design their own procedures for investigations.	0.9%	5.1%	12.8%	42.7%	37.6%	89.7%	9.4%	4.3%	2.6%	32.5%	41.0%	18.8%
19. Students engage in critiquing the procedures that are used when they conduct investigations.	0.9%	5.1%	22.2%	32.5%	36.8%	82.9%	14.5%	2.6%	6.0%	32.5%	37.6%	17.9%
20. Students conduct their own procedures of an investigation.	0.9%	4.3%	25.6%	37.6%	30.8%	84.6%	14.5%	4.3%	4.3%	33.3%	33.3%	22.2%
21. Each student has a role as investigations are conducted	0.9%	6.0%	7.7%	32.5%	53.0%	84.6%	14.5%	3.4%	9.4%	19.7%	29.1%	36.8%
22. When conducting an investigation, students determine which data to collect.	2.6%	14.5%	26.5%	29.9%	25.6%	71.8%	25.6%	7.7%	7.7%	24.8%	31.6%	26.5%
23. When conducting an investigation, students understand why the data they are collecting is important.	0.9%	2.6%	8.5%	24.8%	62.4%	91.5%	6.8%	1.7%	6.0%	23.9%	36.8%	29.9%
24. Students analyse their own data.	1.7%	4.3%	11.1%	39.3%	43.6%	89.7%	9.4%	4.3%	3.4%	20.5%	35.0%	35.0%
25. Students develop their own conclusions for investigations.	0.0%	1.7%	6.8%	35.0%	56.4%	94.0%	5.1%	4.3%	1.7%	17.1%	40.2%	35.9%
26. Students consider a variety of ways of interpreting evidence when making conclusions.	0.0%	2.6%	16.2%	38.5%	41.9%	85.5%	12.8%	1.7%	6.8%	28.2%	35.0%	25.6%
27. Students justify their conclusions.	2.6%	0.9%	9.4%	24.8%	61.5%	90.6%	7.7%	5.1%	2.6%	17.9%	34.2%	39.3%
28. Students present their results and conclusions from an investigation.	0.0%	3.4%	3.4%	35.9%	56.4%	92.3%	6.8%	1.7%	3.4%	17.1%	37.6%	39.3%
29. Students critique information from other sources, e.g. newspapers, web links, magazines	0.9%	3.4%	15.4%	29.1%	51.3%	85.5%	14.5%	4.3%	4.3%	23.1%	35.9%	30.8%
30. Students have opportunities to talk and listen to each other, in the inquiry classroom.	0.0%	1.7%	6.8%	29.9%	61.5%	85.5%	14.5%	3.4%	0.9%	26.5%	29.1%	39.3%
31. Students have opportunities to develop empathy with peers, in the inquiry classroom.	3.4%	4.3%	12.0%	30.8%	48.7%	76.1%	23.9%	6.0%	6.0%	29.1%	24.8%	32.5%
32. Students have the opportunity to respect and understand each other in the inquiry classroom	1.7%	2.6%	9.4%	27.4%	59.0%	81.2%	18.8%	6.0%	6.0%	19.7%	29.9%	37.6%

Table C.5: PSTW – NE/ BE significant differences initially

Statement*	$\chi^2(2)$	P	Mean rank NE	Mean rank BE
1. I have a comprehensive understanding of inquiry-based science education	13.826	.000	36.33	57.81
2. I have a comprehensive understanding of my role as a teacher in an inquiry classroom	6.911	.009	40.46	55.45
3. I have a comprehensive understanding of the role of the students in an inquiry classroom	11.098	.001	37.76	56.31
8. Feedback helps students decide what to include and/or exclude in their work	9.966	.002	61.19	43.60
29A. Students critique information from other sources, e.g. newspapers, web links, magazines	4.671	.031	41.39	54.01
21B. Each student has a role as investigations are conducted	4.542	.033	42.56	53.53
23B. When conducting an investigation, students understand why the data they are collecting is important	6.465	.011	40.82	53.83
24B. Students analyse their own data.	5.449	.020	41.63	53.35
25B. Students develop their own conclusions for investigations	8.866	.003	40.03	55.00
28B. Students present their results and conclusions from an investigation	4.575	.032	42.61	53.50
30B. Students have opportunities to talk and listen to each other, in the inquiry classroom.	13.659	.000	36.86	55.85
31B. Students have opportunities to develop empathy with peers, in the inquiry classroom.	4.810	.028	42.60	52.61
32B. Students have the opportunity to respect and understand each other in the inquiry classroom	6.319	.012	39.96	52.48

*A relates to practice, B relates to what is assessed, C relates to confidence assessing

Table C.6: PSTW – NE/ SE significant differences initially

Statement*	$\chi^2(2)$	P	Mean rank NE	Mean rank SE
1. I have a comprehensive understanding of inquiry-based science education	22.944	.000	28.83	54.06
2. I have a comprehensive understanding of my role as a teacher in an inquiry classroom	10.446	.001	33.71	50.55
3. I have a comprehensive understanding of the role of the students in an inquiry classroom	17.332	.000	30.72	52.02
19A. Students engage in critiquing the procedures that are used when they conduct investigations.	4.995	.025	35.88	47.47
21A. Each student has a role as investigations are conducted	9.346	.002	33.90	49.68
26A. Students consider a variety of ways of interpreting evidence when making conclusions.	8.863	.003	33.46	48.96
27A. Students justify their conclusions.	6.737	.009	34.74	48.04
29A. Students critique information from other sources, e.g. newspapers, web links, magazines	4.221	.040	36.21	46.99
30A.Students have opportunities to talk and listen to each other, in the inquiry classroom.	4.398	.036	35.72	46.36
31A.Students have opportunities to develop empathy with peers, in the inquiry classroom.	4.754	.029	35.34	46.62
32A. Students have the opportunity to respect and understand each other in the inquiry classroom	4.274	.039	35.87	46.62
19C. Students engage in critiquing the procedures that are used when they conduct investigations.	6.528	.011	33.35	46.53
21C. Each student has a role as investigations are conducted	11.836	.001	31.41	49.01
22C. When conducting an investigation, students determine which data to collect	4.841	.028	34.85	46.21
25C. Students develop their own conclusions for investigations	6.441	.011	34.49	47.48
26C. Students consider a variety of ways of interpreting evidence when making conclusions	6.393	.011	34.99	48.14
27C. Students justify their conclusions	8.621	.003	33.86	48.98
30C. Students have opportunities to talk and listen to each other, in the inquiry classroom	4.342	.037	34.84	45.46

*A relates to practice, B relates to what is assessed, C relates to confidence assessing

Table C.7: PSTW – BE/ SE significant differences initially

Statement*	$\chi^2(2)$	P	Mean rank BE	Mean rank SE
5. I have a comprehensive understanding of the nature of assessment in an inquiry classroom	5.238	.022	50.48	63.97
8. Feedback helps students decide what to include and/or exclude in their work	5.981	.014	50.82	64.79
19A. Students engage in critiquing the procedures that are used when they conduct investigations.	4.345	.037	50.63	63.04
21A. Each student has a role as investigations are conducted	6.179	.013	50.09	64.74
23A. When conducting an investigation, students understand why the data they are collecting is important	4.634	.031	51.00	63.57
24A. Students analyse their own data.	5.393	.020	50.59	64.10
25A. Students develop their own conclusions for investigations.*	7.568	.006	49.64	65.32
19B. Students engage in critiquing the procedures that are used when they conduct investigations.	7.217	.007	62.31	48.02
21B. Each student has a role as investigations are conducted	11.661	.001	64.02	45.86
23B. When conducting an investigation, students understand why the data they are collecting is important	8.245	.004	62.84	47.65
24B. Students analyse their own data.	8.636	.003	62.80	47.71
25B. Students develop their own conclusions for investigations	12.235	.000	64.50	46.58
26B. Students consider a variety of ways of interpreting evidence when making conclusions. *	4.538	.033	61.53	50.26
27B. Students justify their conclusions. *	6.876	.009	62.39	49.20
28B. Students present their results and conclusions from an investigation	7.438	.006	62.25	48.09
30B. Students have opportunities to talk and listen to each other, in the inquiry classroom.	17.330	.000	66.44	44.18
31B. Students have opportunities to develop empathy with peers, in the inquiry classroom.	11.645	.001	64.16	47.00
32B. Students have the opportunity to respect and understand each other in the inquiry classroom	11.659	.001	64.12	46.09
17C. Time is devoted to refining student questions so that they can be answered by investigations	7.834	.005	47.93	64.33
19C. Students engage in critiquing the procedures that are used when they conduct investigations.	6.011	.014	49.26	63.86
21C. Each student has a role as investigations are conducted	13.159	.000	46.35	67.77
23C. When conducting an investigation, students understand why the data they are collecting is important	4.821	.028	49.90	62.73
25C. Students develop their own conclusions for investigations	5.361	.021	50.17	63.66
26C. Students consider a variety of ways of interpreting evidence when making conclusions	4.137	.042	50.79	62.83
30C. Students have opportunities to talk and listen to each other, in the inquiry classroom	7.790	.005	48.39	65.03
31C. Students have opportunities to develop empathy with peers, in the inquiry classroom.	3.923	.048	50.53	62.16
32C. Students have the opportunity to respect and understand each other in the inquiry classroom	6.958	.008	48.7	64.08

*A relates to practice, B relates to what is assessed, C relates to confidence assessing

Table C.8: PSTWO – NE/ BE significant differences initially

Statement	$\chi^2(2)$	P	Mean rank NE	Mean rank BE
1. I have a comprehensive understanding of the role of the students in an inquiry classroom	7.643	.006	48.49	64.26
5. I have a comprehensive understanding of the nature of assessment in an inquiry classroom	4.769	.029	60.00	47.89
28A . Students present their results and conclusions from an investigation	4.044	.044	60.37	49.34
30A.Students have opportunities to talk and listen to each other, in the inquiry classroom.	4.366	.037	61.04	49.74
31A.Students have opportunities to develop empathy with peers, in the inquiry classroom.	13.491	.000	65.00	43.84
32A. Students have the opportunity to respect and understand each other in the inquiry classroom	8.055	.005	62.77	47.17
17B. Time is devoted to refining student questions so that they can be answered by investigations	10.984	.001	48.96	63.59
20B. Students conduct their own procedures of an investigation	4.819	.028	52.55	61.07
28B. Students present their results and conclusions from an investigation	4.465	.035	53.66	59.57
31B. Students have opportunities to develop empathy with peers, in the inquiry classroom.	5.341	.021	52.19	62.91
32B. Students have the opportunity to respect and understand each other in the inquiry classroom	5.031	.025	52.69	62.18
17C. Time is devoted to refining student questions so that they can be answered by investigations.	4.068	.044	60.86	48.88
30C. Students have opportunities to talk and listen to each other, in the inquiry classroom.	5.323	.021	61.50	47.93
31C. Students have opportunities to develop empathy with peers, in the inquiry classroom.	9.448	.002	62.97	44.71
32C. Students have the opportunity to respect and understand each other in the inquiry classroom	8.665	.003	63.08	45.61

*A relates to practice, B relates to what is assessed, C relates to confidence assessing

Table C.9: Significant differences between PTSW and PTSWO initially

Statement	$\chi^2(2)$	P	Mean rank PSTW	Mean rank PSTWO
1. I have a comprehensive understanding of inquiry-based science education	4.429	.035	142.32	123.00
7. Giving students feedback is important because it helps them to learn	5.972	.015	142.23	121.86
10. The point of feedback is to make students feel good about themselves	18.355	.000	115.88	154.71
16. Students formulate questions which can be answered by Investigation	16.512	.000	116.39	153.37
17. Time is devoted to refining student questions so that they can be answered by investigations.	25.249	.000	112.29	158.28
18. Students design their own procedures for investigations.	35.260	.000	109.19	163.58
19. Students engage in critiquing the procedures that are used when they conduct investigations.	36.604	.000	106.55	161.65
20. Students conduct their own procedures of an investigation.	42.206	.000	105.68	165.02
21. Each student has a role as investigations are conducted	29.490	.000	110.21	160.05
22. When conducting an investigation, students determine which data to collect.	37.291	.000	106.90	162.94
23. When conducting an investigation, students understand why the data they are collecting is important.	34.31	.000	108.67	162.03
24. Students analyse their own data.	26.933	.000	111.94	159.14
25. Students develop their own conclusions for investigations.	27.192	.000	112.28	159.62
26. Students consider a variety of ways of interpreting evidence when making conclusions.	43.809	.000	106.27	167.01
27. Students justify their conclusions.	25.100	.000	113.52	159.34
28. Students present their results and conclusions from an investigation.	23.808	.000	112.98	157.41
29. Students critique information from other sources, e.g. newspapers, web links, magazines	42.665	.000	105.76	165.77
30. Students have opportunities to talk and listen to each other, in the inquiry classroom.	29.725	.000	110.06	159.80
31. Students have opportunities to develop empathy with peers, in the inquiry classroom.	34.340	.000	108.49	162.26
32. Students have the opportunity to respect and understand each other in the inquiry classroom	21.704	.000	113.18	155.84

Table C.10: Significant changes in PSTW

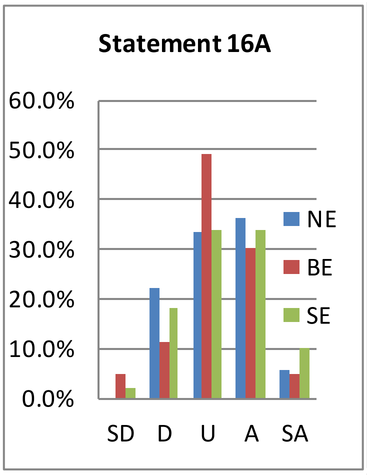
Statement	Z	P
1. I have a comprehensive understanding of inquiry-based science education	-5.802	.000
2. I have a comprehensive understanding of my role as a teacher in an inquiry classroom	-5.319	.000
3. I have a comprehensive understanding of the role of the students in an inquiry classroom	-5.442	.000
4. I am confident using multiple assessment methods	-2.103	.035
5. I have a comprehensive understanding of the nature of assessment in an inquiry classroom	-5.951	.000
6. In an inquiry classroom I can easily highlight strengths and weaknesses of a particular student's work	-3.821	.000
11. Quality feedback happens interactively and immediately in the classroom while students are learning	-2.134	.033
14. Peers are the best source of feedback	-3.347	.001

Table C.11: Significant changes in PSTWO

Statement	Z	P
1. I have a comprehensive understanding of inquiry-based science education	-5.736	.000
2. I have a comprehensive understanding of my role as a teacher in an inquiry classroom	-4.014	.000
3. I have a comprehensive understanding of the role of the students in an inquiry classroom	-4.009	.000
4. I am confident using multiple assessment methods	-2.651	.008
5. I have a comprehensive understanding of the nature of assessment in an inquiry classroom	-4.718	.000
6. In an inquiry classroom I can easily highlight strengths and weaknesses of a particular student's work	-2.666	.008
8. Feedback helps students decide what to include and/or exclude in their work	-3.636	.000
11. Quality feedback happens interactively and immediately in the classroom while students are learning	-2.112	.035
14. Peers are the best source of feedback	-2.105	.035
15. Feedback is a two-way process between the students and the teacher	-2.340	.019

Table C.12: Significant differences between PTSW and PTSWO finally

Statement	$\chi^2(2)$	P	Mean rank PSTW	Mean rank PSTWO
1. I have a comprehensive understanding of inquiry-based science education	8.717	.003	97.73	77.46
2. I have a comprehensive understanding of my role as a teacher in an inquiry classroom	6.924	.009	96.26	79.05
3. I have a comprehensive understanding of the role of the students in an inquiry classroom	7.651	.006	96.08	78.10
7. Giving students feedback is important because it helps them to learn	6.208	.013	95.91	79.43
9. Time spent giving feedback is a wasted effort	13.511	.000	75.59	100.26
10. The point of feedback is to make students feel good about themselves	11.045	.001	76.30	100.68
17. Time is devoted to refining student questions so that they can be answered by investigations.	12.388	.000	73.69	99.05
18. Students design their own procedures for investigations.	13.038	.000	74.61	100.13
19. Students engage in critiquing the procedures that are used when they conduct investigations.	10.103	.001	75.49	98.30
21. Each student has a role as investigations are conducted	8.954	.003	76.66	98.21
22. When conducting an investigation, students determine which data to collect.	9.263	.002	75.90	97.86
23. When conducting an investigation, students understand why the data they are collecting is important.	16.253	.000	72.17	101.01
24. Students analyse their own data.	9.812	.002	75.73	98.05
25. Students develop their own conclusions for investigations.	4.200	.040	79.44	93.89
26. Students consider a variety of ways of interpreting evidence when making conclusions.	5.844	.016	78.54	95.96
27. Students justify their conclusions.	8.865	.003	76.48	97.24
28. Students present their results and conclusions from an investigation.	4.200	.040	77.81	92.04
29. Students critique information from other sources, e.g. newspapers, web links, magazines	16.677	.000	71.79	101.43
30. Students have opportunities to talk and listen to each other, in the inquiry classroom.	13.294	.000	72.10	98.36
31. Students have opportunities to develop empathy with peers, in the inquiry classroom.	12.167	.000	73.63	99.12
32. Students have the opportunity to respect and understand each other in the inquiry classroom	7.614	.006	76.72	96.98


Statement 16A
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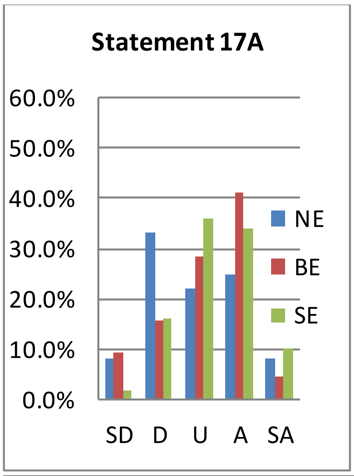
Statement 17A
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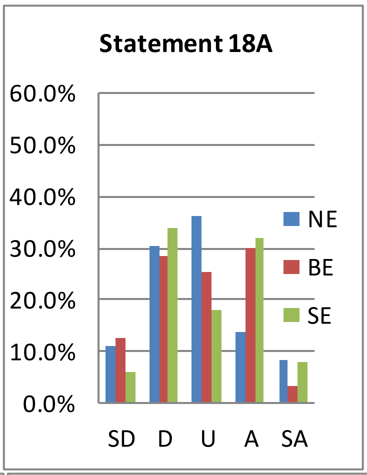
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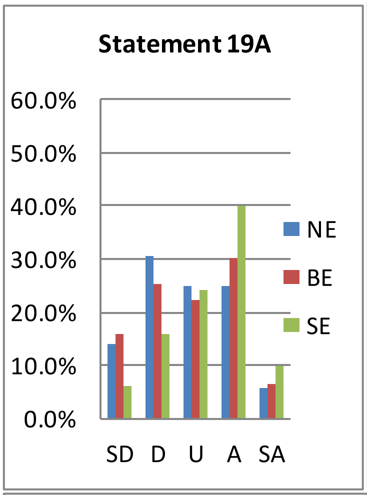
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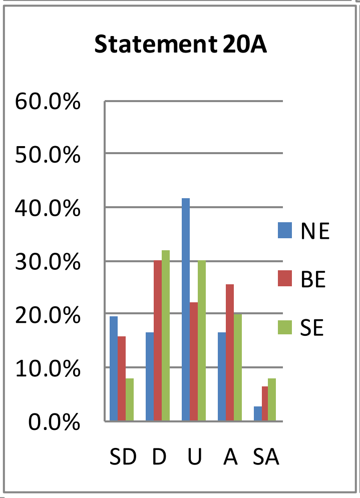
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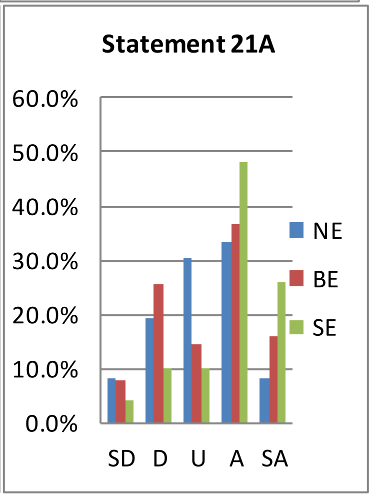
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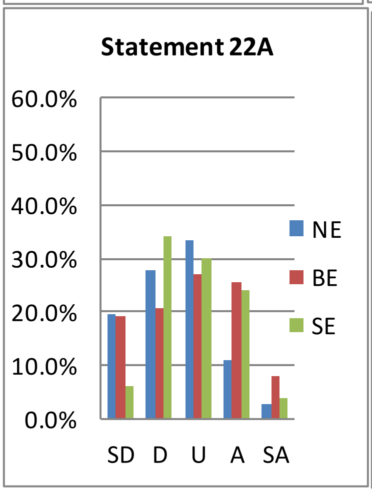
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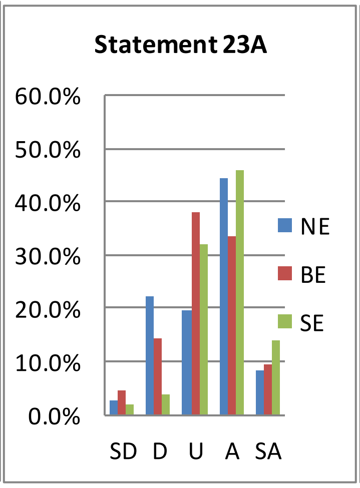
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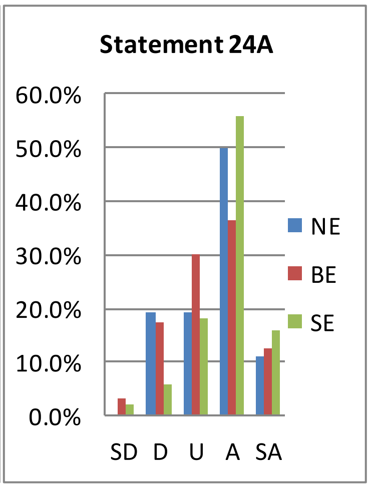
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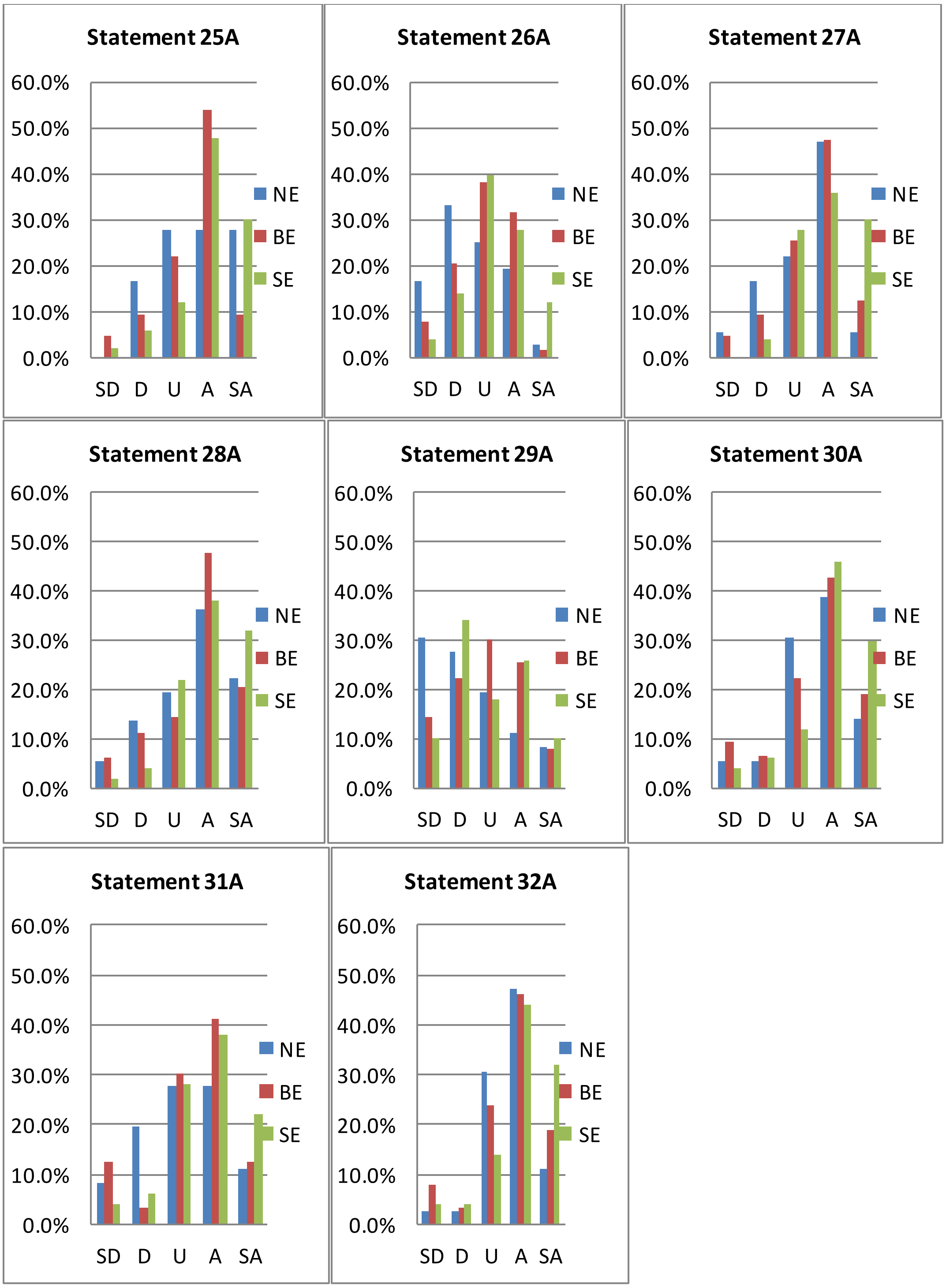
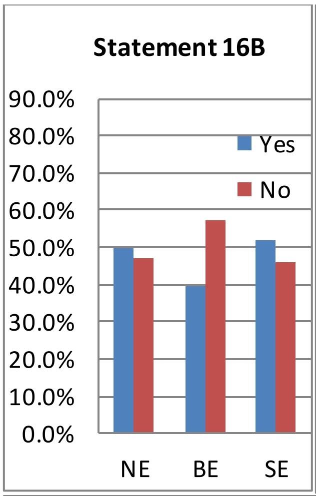


Figure C.1: PSTW - Responses to questions relating to inquiry practices, based on individual teacher experience in IBSE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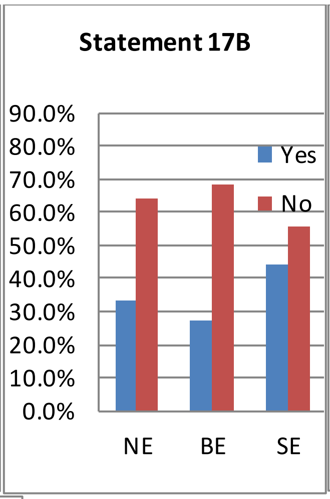
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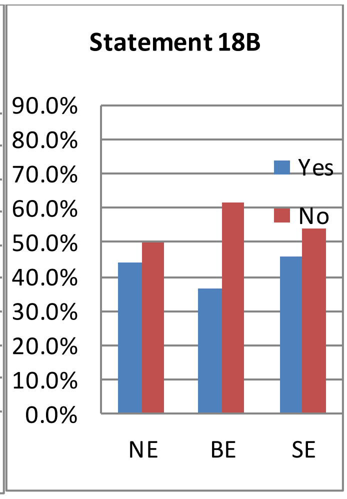
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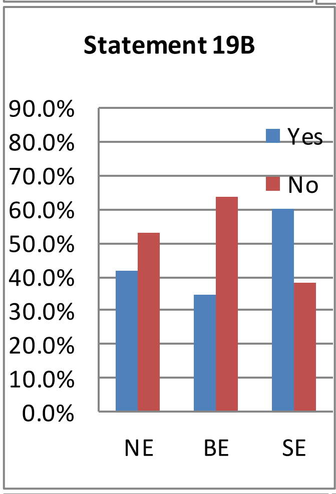
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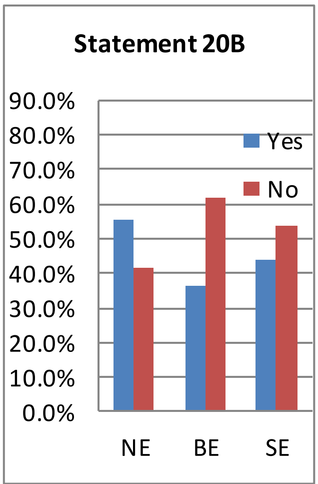
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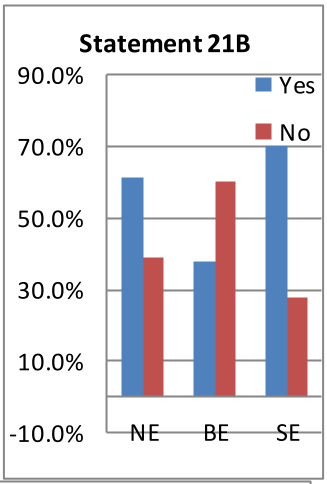
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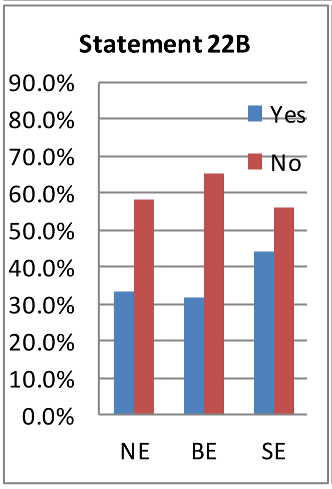
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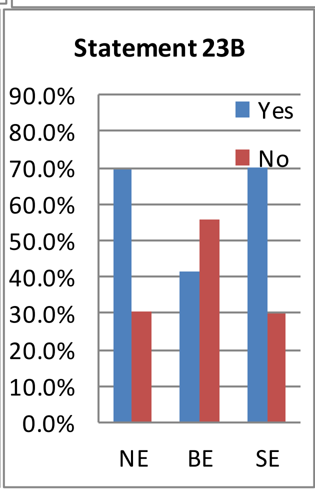
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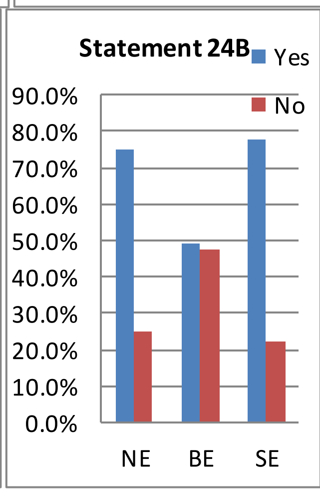
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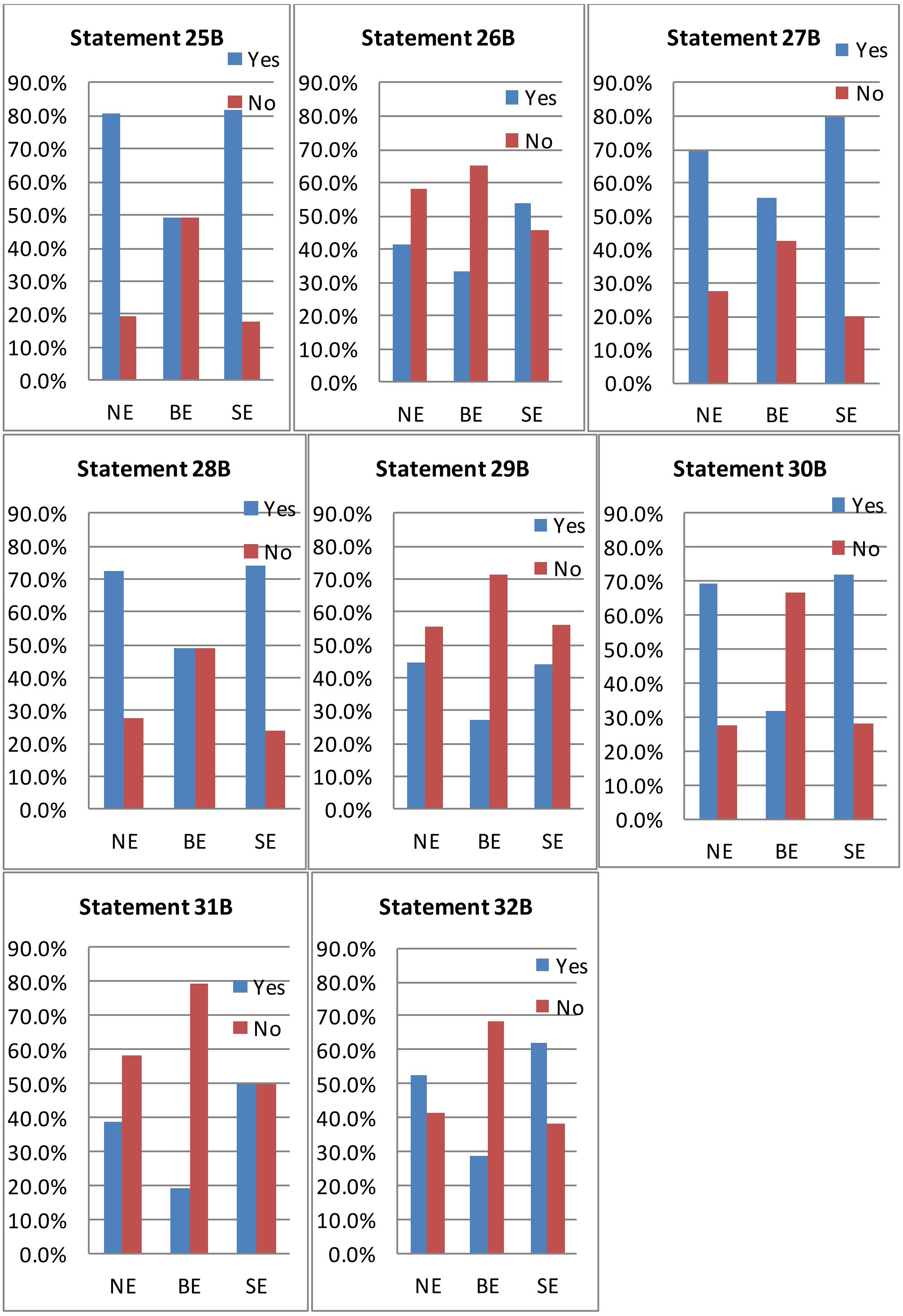
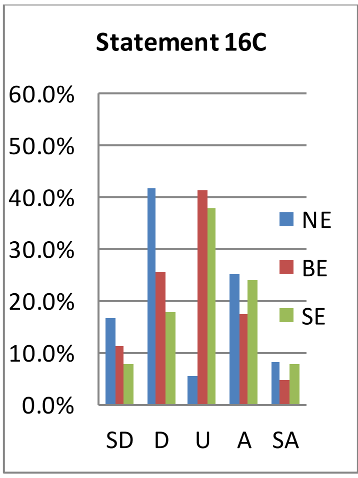


Figure C.1: PSTW Responses to questions relating to inquiry practices assessed, based on individual teacher experience in IBSE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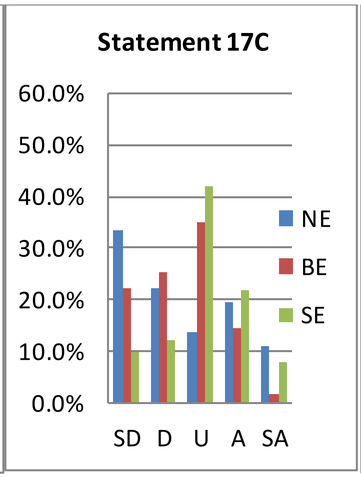
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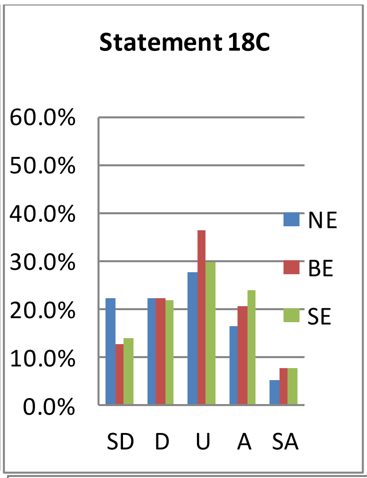
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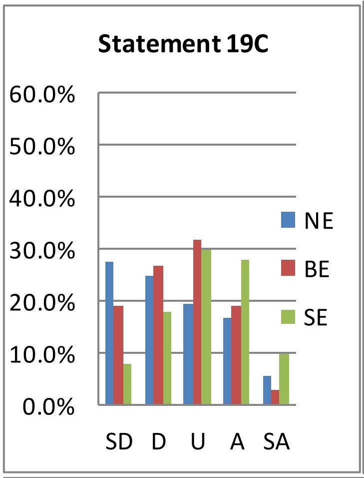
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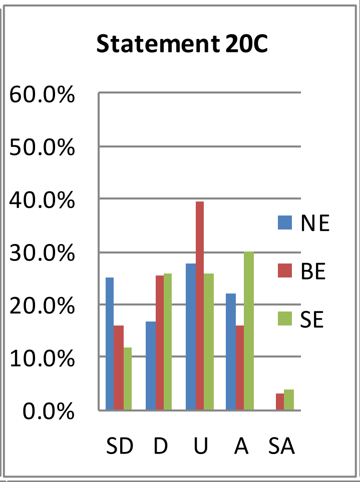
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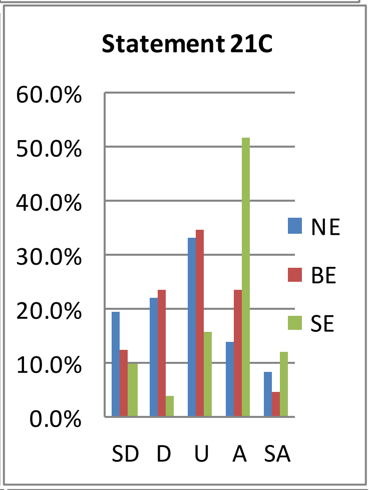
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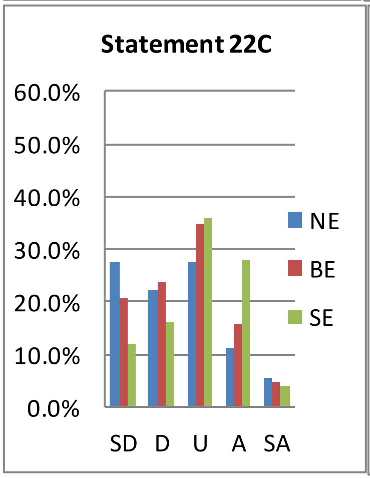
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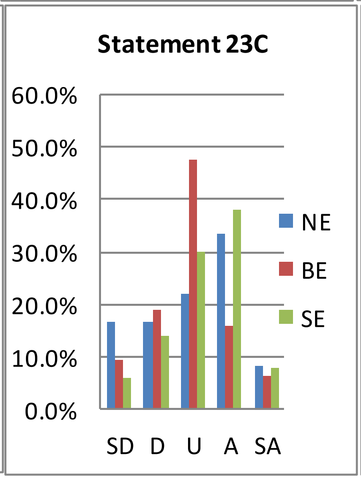
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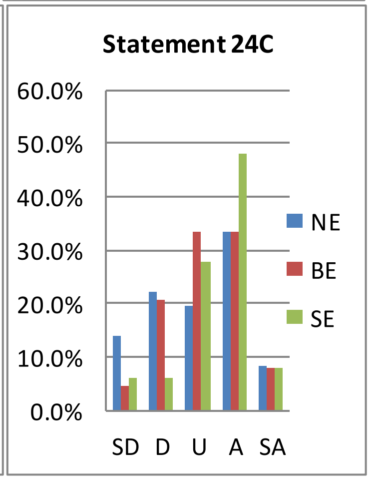
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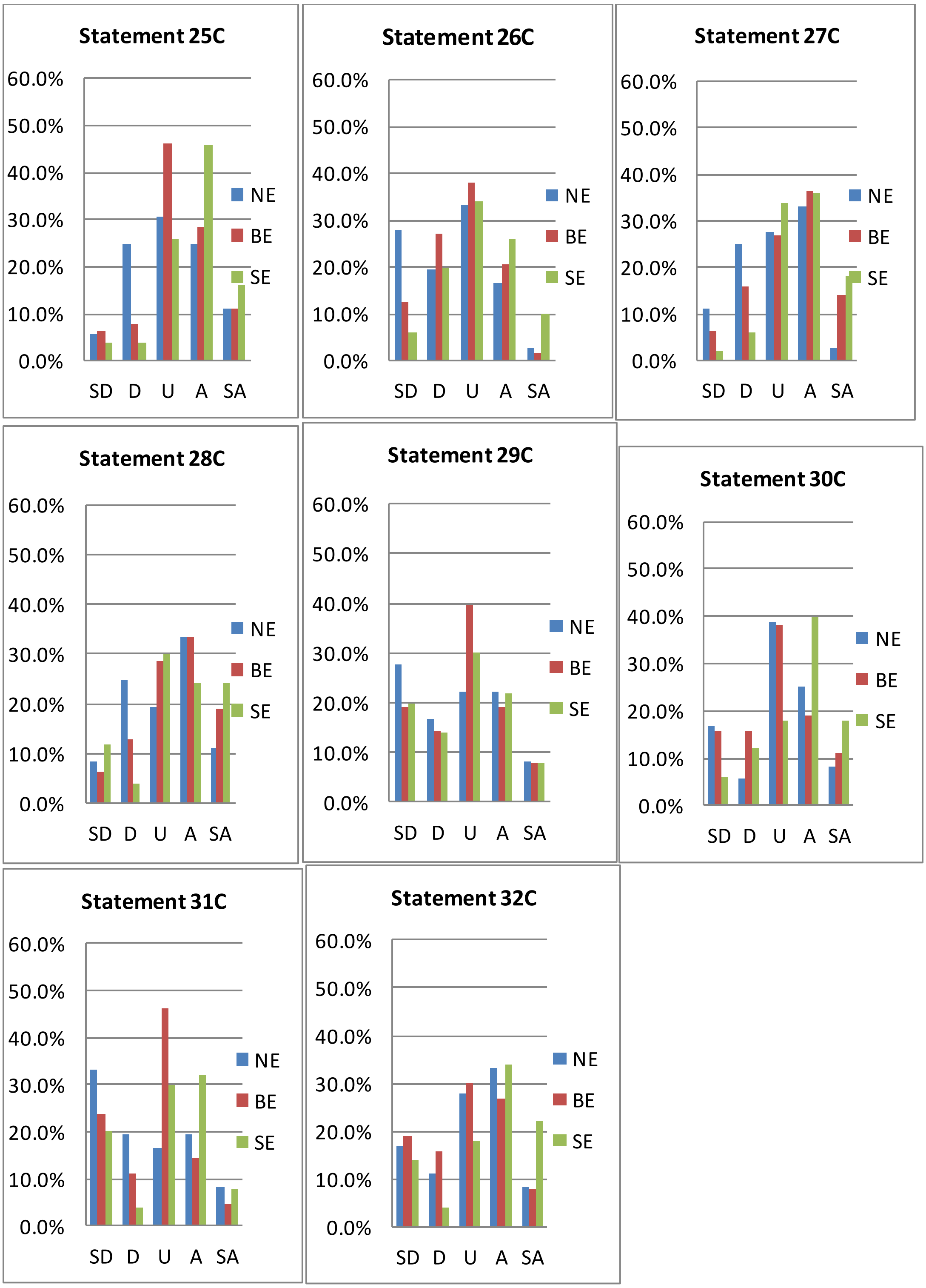
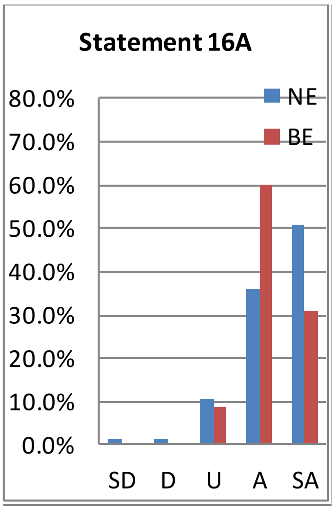


Figure C.2: PSTW - Responses to questions relating to confidence assessing inquiry, based on individual teacher experience in IBSE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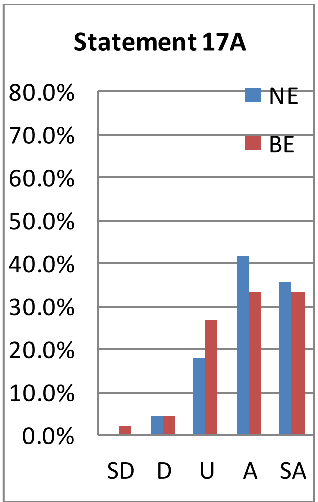
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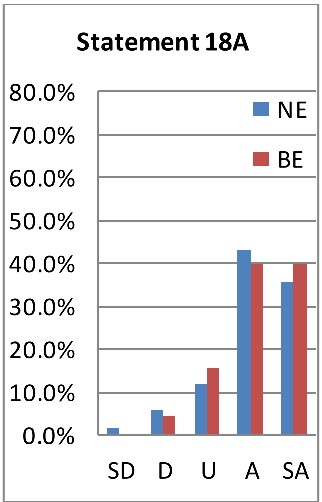
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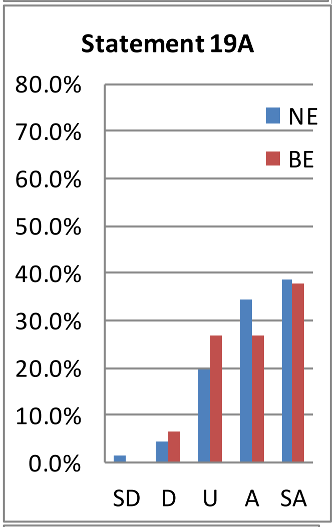
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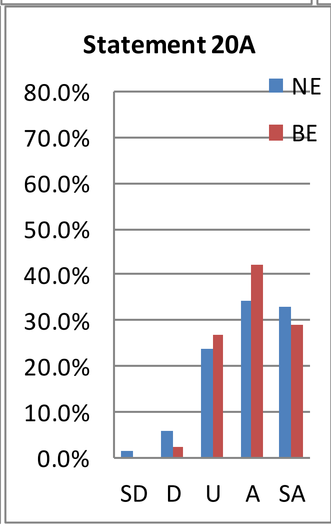
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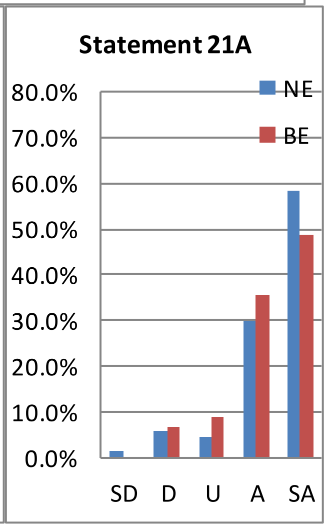
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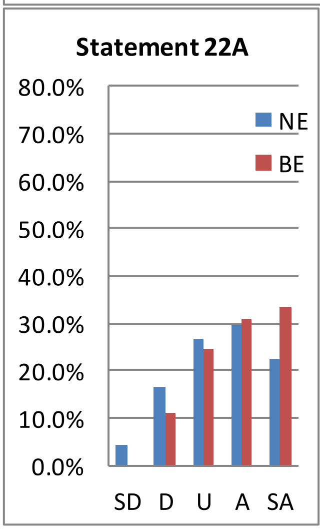
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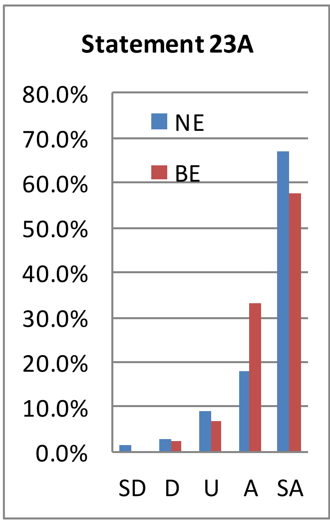
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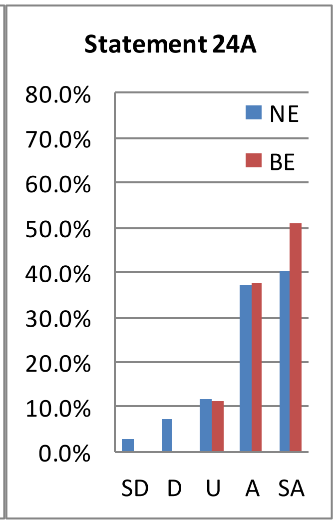
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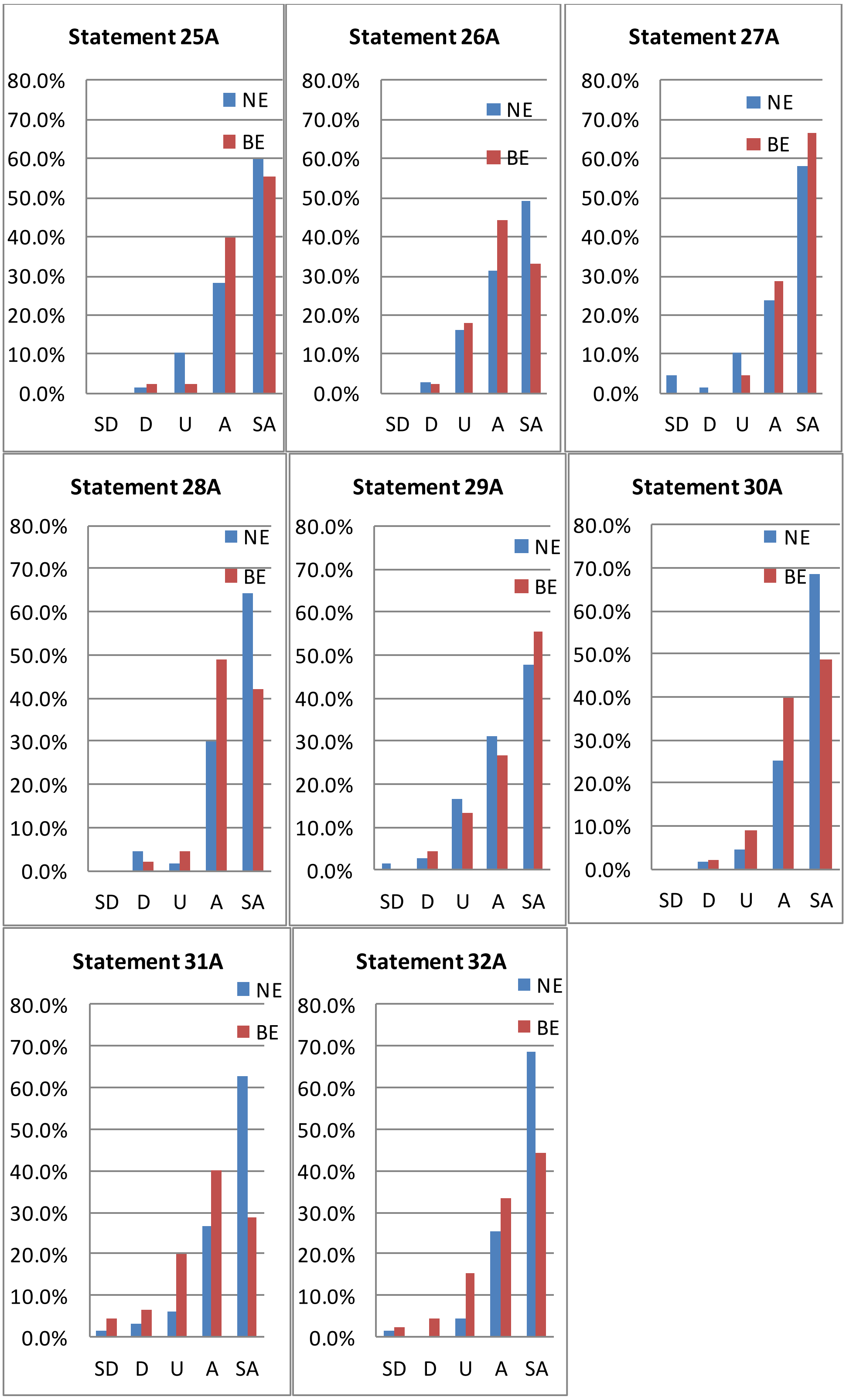
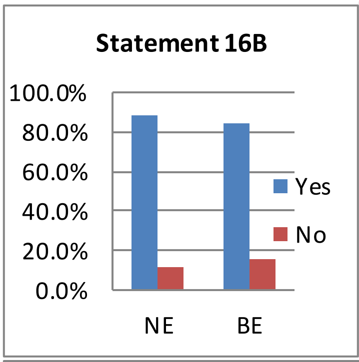


Figure C.3: PSTWO - Responses to questions relating to inquiry practices, based on individual teacher experience in IBSE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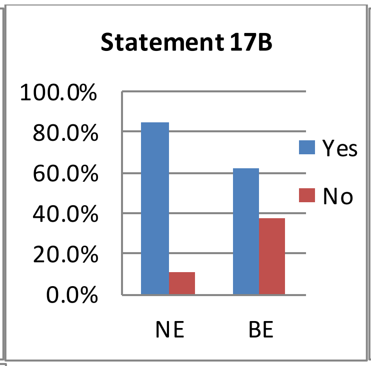
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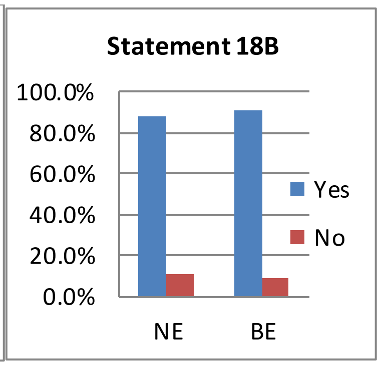
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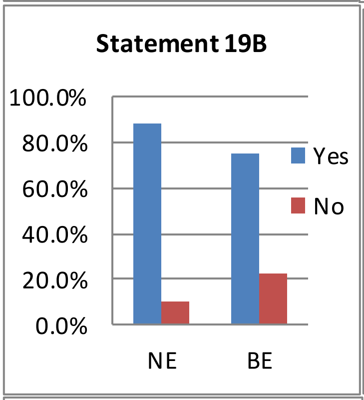
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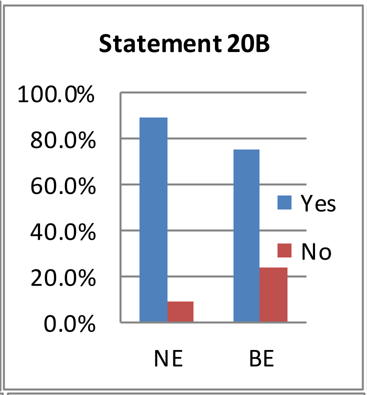
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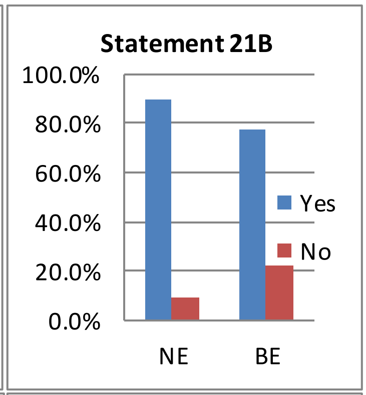
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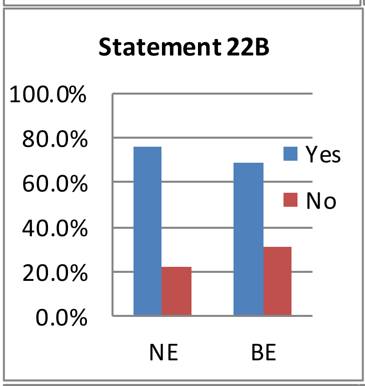
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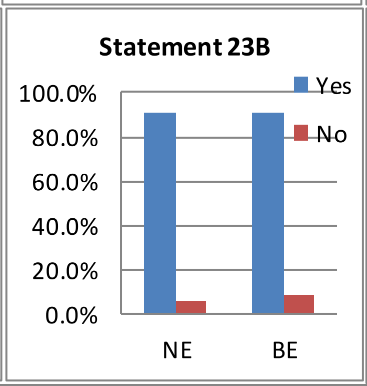
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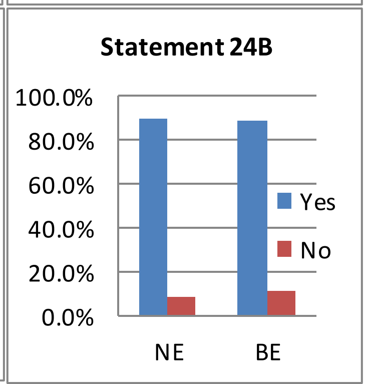
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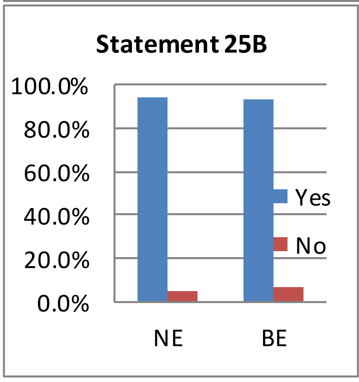
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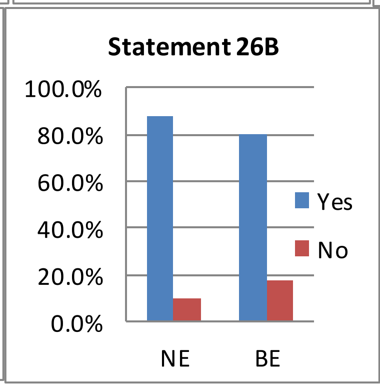
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Yes
No
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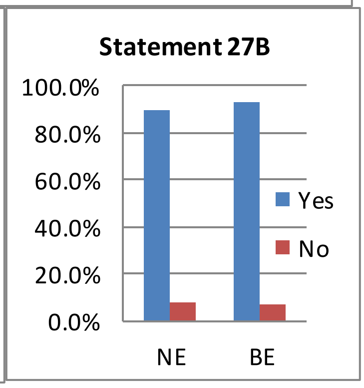
Statement 27B
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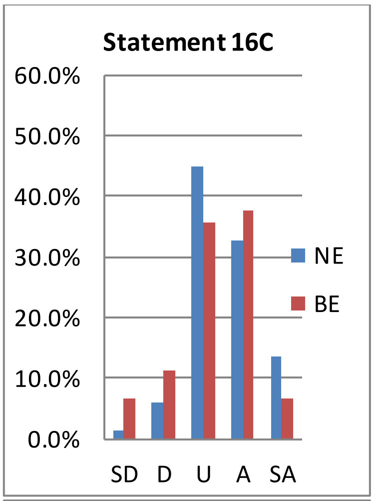
Figure C.4: PSTWO Responses to questions relating to inquiry practices assessed, based on individual teacher experience in IBSE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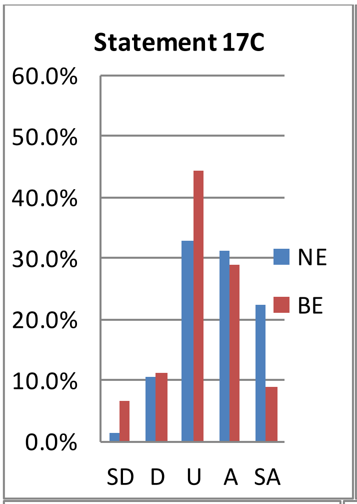
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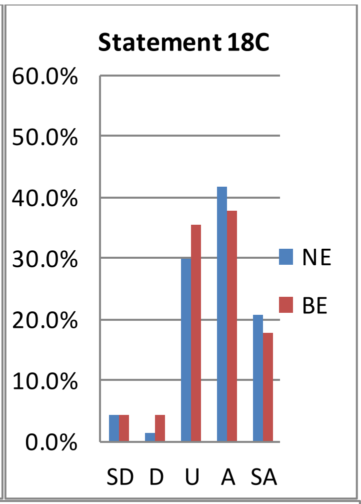
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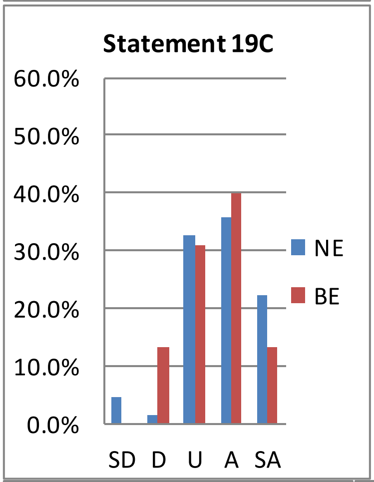
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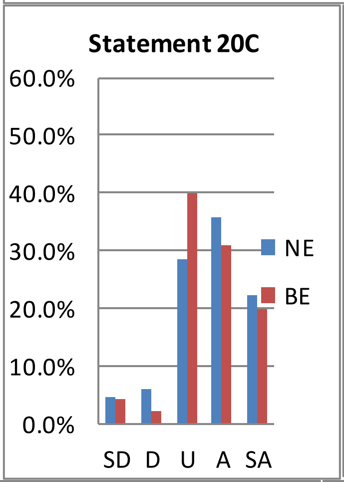
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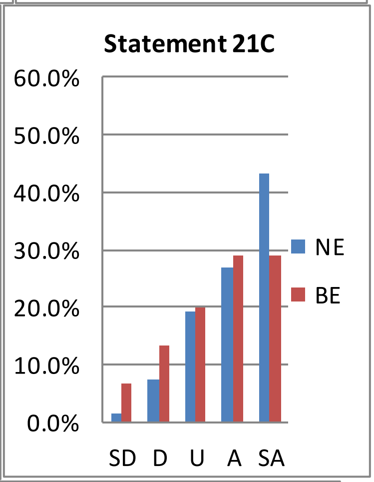
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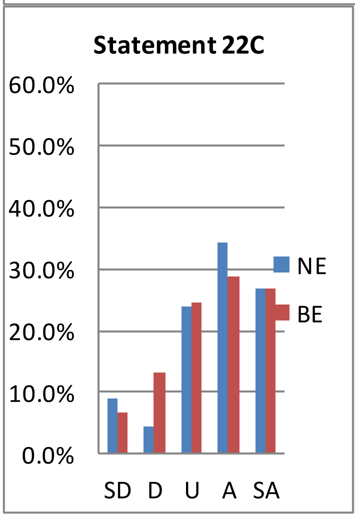
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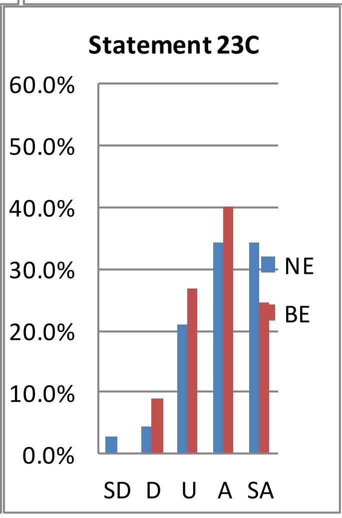
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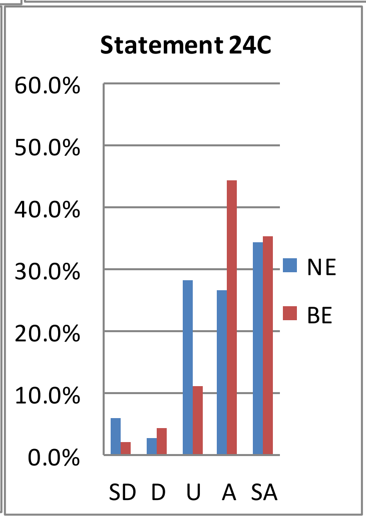
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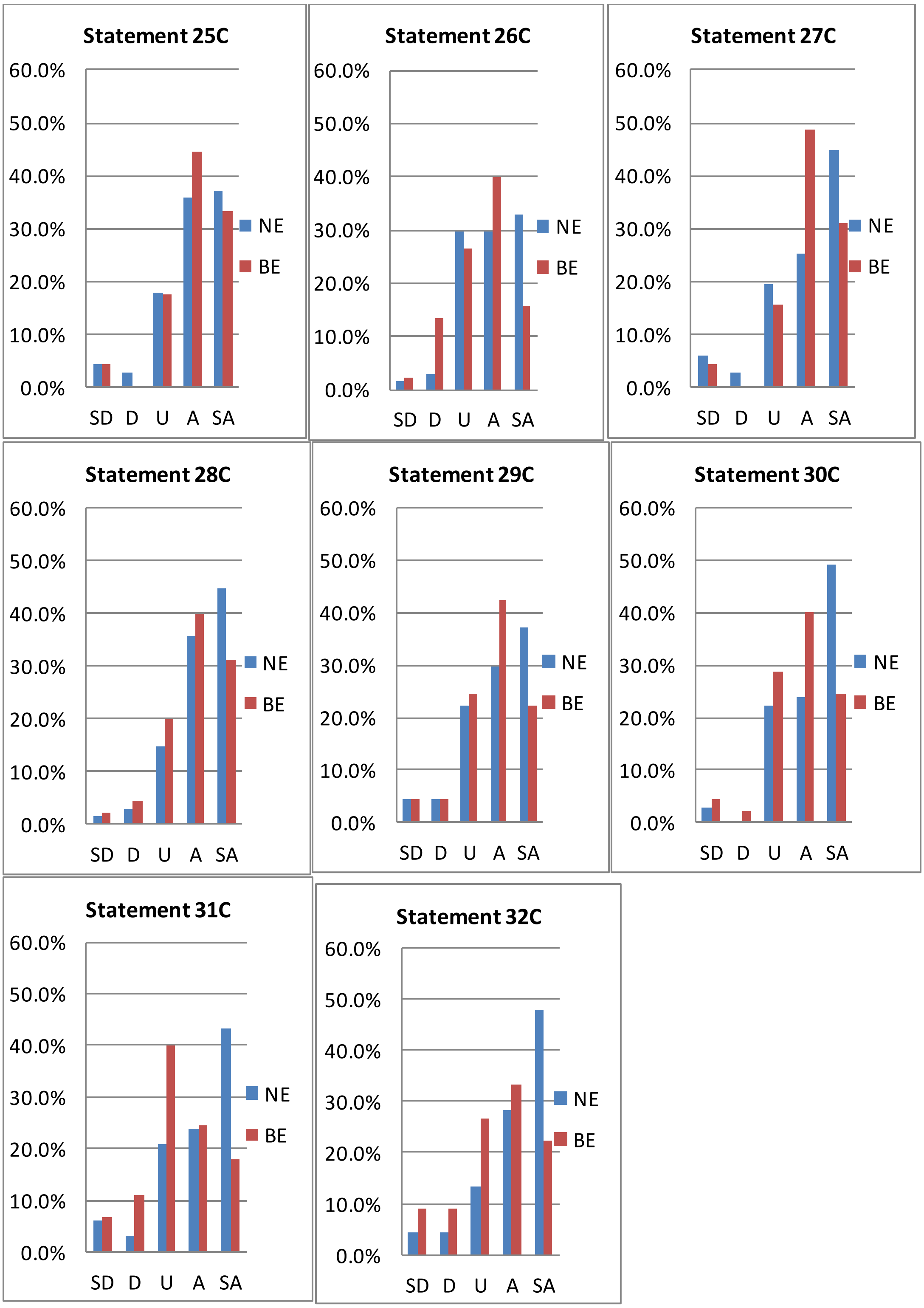

Figure C.5: PSTWO Responses to questions relating to confidence assessing inquiry, based on individual teacher experience in IBSE

Table C.13: PSTW Correlations

	A w/ B	A w/ C	B w/ C
16. Students formulate questions which can be answered by Investigation	-.165*	.342**	-.338**
17. Time is devoted to refining student questions so that they can be answered by investigations.	-.423**	.548**	-.415**
18. Students design their own procedures for investigations.	-.327**	.454**	-.345**
19. Students engage in critiquing the procedures that are used when they conduct investigations.	-.210*	.421**	-.360**
20. Students conduct their own procedures of an investigation.	-.272**	.386**	-.303**
21. Each student has a role as investigations are conducted	-.392**	.573**	-.486**
22. When conducting an investigation, students determine which data to collect.	-.388**	.534**	-.426**
23. When conducting an investigation, students understand why the data they are collecting is important.	-.143	.366**	-.411**
24. Students analyse their own data.	-.202*	.487**	-.365**
25. Students develop their own conclusions for investigations.	-.255**	.455**	-.319**
26. Students consider a variety of ways of interpreting evidence when making conclusions.	-.330**	.540**	-.428**
27. Students justify their conclusions.	-.305**	.600**	-.332**
28. Students present their results and conclusions from an investigation.	-.333**	.616**	-.330**
29. Students critique information from other sources, e.g. newspapers, web links, magazines	-.434**	.617**	-.536**
30. Students have opportunities to talk and listen to each other, in the inquiry classroom.	-.209*	.452**	-.452**
31. Students have opportunities to develop empathy with peers, in the inquiry classroom.	-.285**	.603**	-.466**
32. Students have the opportunity to respect and understand each other in the inquiry classroom	-.283**	.560**	-.563**

A w/B Correlations between inquiry practices and assessment, A w/ C Correlations between inquiry practices and confidence, B w/ C Correlations between assessment and confidence

*p<.05, **p<.01