Pre-Service Science Teachers' Professional Vision of Inquiry - A Design Based Research Study

Author

Paul Grimes B.Sc. (Hons)

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Research Supervisors

Dr. Paul van Kampen

Dr. Eilish McLoughlin

Dr. Odilla Finlayson

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, 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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ID No.:

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List of publications

Papers

McDonald, S., Grimes, P., Doughty, L., Burke, N., Finlayson, O., McLoughlin, E. & van Kampen, P.: *Professional Pedagogical Vision and the Impact on Irish Secondary Science Teacher Candidates of an Apprenticeship of Observation* **(In Preparation)**

Anticipated Papers

Exploring Discourse and Explanations among Pre-service Science Teachers in Ireland (Chapter 5)

Comparing the Highlighting and Coding Practices of Pre-service Teachers in Ireland and the USA (Chapter 4)

Conference Presentations

Grimes, P., McDonald, S., Doughty, L. & van Kampen P.: *Preparing Irish Secondary Science Teachers for Inquiry-based Science Education*, AAPT Summer Meeting, Minneapolis, MN, June 2015

Grimes, P., McDonald, S., McLoughlin E., Finlayson, O. & van Kampen P.: *Professional Vision of Inquiry Based Science Education: A perspective from Ireland and the U.S.* ESERA 2015, Helsinki, September 2015

Grimes, P., McLoughlin E., Finlayson, O. & van Kampen P.: *Patterns of Discourse in Pre-service Teachers' Explanations*. SMEC 2016, Dublin, June 2016

Workshops

McLoughlin, E., van Kampen, P., Grimes, P.: *Talking about light in the inquiry classroom*. Frontiers in Physics Conference, Dublin, September 2014

Grimes, P., McLoughlin E., Finlayson, O. & van Kampen P.: *Teacher-Student Dialogue in the Inquiry Classroom.* SMEC 2014, Dublin, June 2014

Poster Presentations

Grimes, P., McLoughlin, E., & van Kampen, P.: *Learning to teach physics: What do prospective teachers 'see'?* Dublin City University School of Physical Sciences BOC Poster Competition, April 2015

Research Communication Competitions

Grimes, P.: *Inspiring Physics: New Teachers, New Ideas* Dublin City Universtiy Tell it Straight Competition Final, April 2014

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Abstract

This work reports on a Design Based Research study that investigated the development of a module for pre-service science teachers at an Irish university. The module aimed to broaden pre-service science teachers' views of science teaching, and to extend the types of teaching they experienced as students. Qualitative methods were used to establish the pre-service teachers' views through the lens of Professional Vision.

The Design Experiment consisted of three Design Cycles that were used in successive years. In the first Design Cycle the pre-service science teachers first experienced and then critiqued five workshops in which a number of mostly guided inquiry activities suited for the lower secondary classroom were used. Analysis of this cycle established a first evaluation of Irish pre-service teachers' Professional Vision. On foot of this analysis Cycles 2 and 3 incorporated a video analysis workshop and a workshop in which participants learned unfamiliar content through inquiry. In Cycle 3, a new analysis framework was developed that combines argumentation, sense-making and transactivity. This framework was used to investigate the type of discourse the pre-service teachers engaged in while carrying out an open inquiry activity. Their interpretation of a videotaped class in which a group of lower secondary school students engaged in the same activity was also analysed. The results and conclusions of each of the Design Cycles are used to make recommendations for future directions of the module.

Chapter 1 Introduction

In a paper exploring school science in a historical context, Rudolph (2003) remarks that as far back as 1909, John Dewey noted that "instruction in scientific thinking, not science *per se*, should be the primary aim of the science teacher" (Dewey, 1909, p. 291)" (Rudolph, 2003; p. 69). This importance of instruction in scientific thinking has been reflected in the focus over the past three decades on Inquiry Based Science Education (IBSE). Inquiry and IBSE have many different definitions, some of which are context dependant. For example inquiry can be used both to describe the way in which scientists work, and a method through which student learn (Barrow, 2006). Common to all of these is the belief that students must think scientifically. In order to do this, teachers must design instruction and activities that give students the opportunity to think scientifically.

Inquiry is at the heart of this thesis. More specifically, the thesis outlines the development and refinement of a module taken by Pre-service science Teachers (PTs) during the second year of their studies at an Irish university. A primary goal of the module was and is for PTs to experience and reflect on inquiry activities designed for use in the secondary science classroom.

This chapter gives an overview of the thesis, explaining its layout and what its primary aims are. Along with this a timeline for the research is presented, linking learning and research cycles to the module.

1.1 Science Education in Ireland

1.1.1 Secondary Science in Ireland

Science education at lower secondary level in Ireland is currently in a state of change. While this research took place, second level students of science studied the revised Junior Certificate Science Syllabus (rJCSS), introduced in 2003. All of the PTs in this study have experienced the rJCSS as students, which played a large part in their cultural experiences of science teaching and their Apprenticeship of Observation (Lortie, 1975).

The syllabus PTs experienced while they were students was designed to align well with inquiry. A report published shortly after its introduction by Eivers, Shiel, & Cheevers (2006) noted that

> "The revised Junior Certificate Science Syllabus (rJCSS) [places]…greater emphasis on student investigation and practical work, designed to help students develop an understanding of science concepts, as well as acquire the necessary science process skills" (p. 3)

In this syllabus there is an emphasis on practical activities. The syllabus differentiates between two different types of practical activities: experiments and investigations. It outlines that experiments allow students to use a prescribed procedure to discover an unknown. Along with this, the purpose of experiments is

> "…to make scientific phenomena more real to students and provide them with opportunities to develop manipulative skills and safe work practices in a school laboratory" (Department of Education and Science, 2003, p. 7.)

Investigations, on the other hand, are designed to give students an experience where they can gather information about a process or an event "in a manner that is not pre-determined in either procedure or outcome" (Department of Education and Science, 2003). They can be used to

> "…develop skills of logical thinking and problem solving, and can give the student an insight into the scientific process." (p. 7)

Moreover, the syllabus states among its objectives that

> "students will develop skills associated with
> - […]
> - procedural plans and the use of the scientific method in problem solving
> - […]
> - obtaining and using information from a variety of sources
> - […]
> - logical thinking, inductive and deductive reasoning, and the formation of opinions and judgments based on evidence and experiment
> - […]
> - independent study and co-operative learning" (p. 4-5)

All of the above aims align well with teaching and learning by inquiry methods. However, while the syllabus has aims that indicate that inquiry would be commonplace in the science classroom, this is typically not the case. A number of factors contribute to this. Eivers et al. (2006) described how the content-heavy nature of the syllabus results in time constraints restricting the engagement of inquiry in the classroom. Along with this, learning outcomes are very prescriptive which can contribute to an overemphasis on learning precise facts. This is perhaps reflected in the teaching styles of Irish post-primary teachers. Gleeson (2012) reported that the analysis of research evidence suggests that Irish post-primary teachers employ a mostly didactic style of teaching. Gleeson also summarises Sheehan's (2003) study of Junior Certificate Science teaching. Sheehan's study found that teaching at Junior Certificate Science focused on content and examinations. The TALIS report (2009) also reports that in Ireland a transmission style of teaching is quite normal in classrooms.

The exam focused nature of the syllabus can also lead to a 'washback' effect. Before entering third level education, all of the PTs' formal education as students was spent in this system. Their initial understandings of teaching and science teaching will reflect this.

At present, however, science at junior secondary level is in a process of change. This change started with the publication of the Junior Cycle Framework (Department of Education and Skills, 2013). Conceptually, Junior Cycle

> "…allows students to make a greater connection with learning by focusing on the quality of learning that takes place, and by offering experiences that are engaging and enjoyable for them, and are relevant to their lives." (p. 3)

From a science perspective the new junior cycle places a greater emphasis on the nature of science. The specification outlines that

> "Science in junior cycle aims to develop students' evidence-based understanding of the natural world and their ability to gather and evaluate evidence: to consolidate and deepen their skills of working scientifically; to make them more self-aware as learners and become competent and confident in their ability to use and apply science in their everyday lives." (Department of Education and Skills, 2013, p. 5)

The introduction of a new syllabus or specification presents a challenge for all teachers, including PTs. PTs will be entering their professional careers in a system that is different to the one that they had experienced as a second level student. The new specification, which came into force in September 2016, is much less tightly defined and comprises 45 learning outcomes that balance an expectation of students to have acquired both declarative knowledge and inquiry skills (NCCA, 2014). As PTs, each module that they undertake will be designed to prepare them for the new curriculum; however, they will still have their underlying apprenticeship of observation from their own time as a second level student.

1.1.2 Science Teacher Education in Ireland

At present, there are two models of second level teacher education in Ireland: the consecutive model and the concurrent model. In the consecutive model of teacher education, students enrolling in the programme are required to have a primary degree in a relevant area. They then enrol in a postgraduate programme of teacher education, typically for 2 years. The postgraduate programme usually contains some content specific pedagogy modules, bur mostly the focus is on general pedagogy and professionalism in teaching. Students in these programmes also carry out school placements at different stages over the two years. Consecutive models of teacher education are built on the assumption that PTs' content knowledge and beliefs are built up in their primary degree, prior to the teacher education programme (Paolucci, 2015). Traditionally, this was the most common pathway into second level teaching in Ireland.

More recently, there has been a rise in the number of undergraduate, concurrent teacher education programmes. Students who enrol in concurrent programmes usually decide to do so immediately after they have completed second level education. Concurrent programmes allow PTs to complete content only modules and pedagogy focused modules concurrently. The PTs in this research are enrolled in a concurrent B.Sc. in Science Education programme at an Irish University. PTs who complete this degree are qualified to teach lower secondary Science (Junior Cycle, students typically aged 12-15) and senior cycle Physics, Chemistry or Maths (Leaving Certificate, students typically aged 16-18).

1.2 Personal Views on Science Teaching

Through my experience of science education as both a student and a researcher, I have formed a view of science education that has been informed by lecturers, research and practice. It is my own view that science teaching should not be about the transmission of facts or procedures. Students of science should get the opportunity to appreciate the nature of science, and ask questions about what they are doing. They should be allowed to explore scientific phenomena in detail, and draw conclusions based on observations and measurements. The science classroom should be a place where students work together, and use each other's ideas to help further their knowledge and understanding of the subject. Students should also be afforded opportunities to present what they are doing and learning about in a number of ways. In my opinion, the importance of talk and collaboration in the science classroom cannot be underestimated.

Throughout this study, my role was that of a researcher and a teacher. To the best of my ability, I have tried to reflect my own view of science teaching while interacting with groups of PTs during the workshops. Throughout the thesis, I tend to use the word "we" rather than "I". This reflects the fact that while I was the lead researcher and ultimately made the decisions on the direction the research took and the types of analysis undertaken, the work would not have been possible without the collaboration with other researchers.

1.3 A Rationale for the Study

With the introduction of a new Junior Cycle specification for Science, it is crucial for PTs to experience and reflect on inquiry activities. We therefore designed a module[1] with the aim of broadening the PTs' views of science teaching and extending the kinds of teaching they had experienced themselves as students. In technical terms, we were

[1] The "module" mentioned in this thesis is a set of 8 three-hour laboratory-based workshops with a strong PCK focus. For administrative reasons, these were lumped together with a set of computer-based labs and a set of traditional physics labs under the umbrella of "module" IBSE101 (a pseudo module code used throughout the thesis to preserve anonymity of the institution and the research participants). For the purposes of this thesis, when we refer to "IBSE101" we mean these PCK workshops only.

broadening their Professional Vision (PV) and extending their Apprenticeship of Observation. These aims are as important as ever. PTs must be prepared to teach in classrooms where students are allowed to work scientifically. They must also be able to support students to "become competent and confident in their ability to use and apply science in their everyday lives". However, the desired outcomes of IBSE101 are designed to be broader than just preparing PTs to 'teach the new Junior Cycle': by engaging PTs in inquiry, and allowing them to critique and reflect on it, we hope that they will acquire the mindset, the tools and the confidence to enact inquiry in their classrooms.

Investigating the effects of IBSE101, and investigating how IBSE101 develops over time has helped to better achieve these aims. The investigation would also inform us in more detail how PTs learn about inquiry, and how to teach by inquiry.

We do not simply equate inquiry with 'good teaching', but note that inquiry aligns well with it. For example, in his synthesis of over 800 meta-analyses, Hattie (2009, p. 238) identified six 'signposts towards excellence in education':

1. Teachers are among the most powerful influences in learning.
2. Teachers need to be directive, influential, caring, and actively and passionately engaged in the process of teaching and learning.
3. Teachers need to be aware of what each and every student in their class is thinking and what they know, be able to construct meaning and meaningful experiences in light of this knowledge of the students, and have proficient knowledge and understanding of their subject content so that they can provide meaningful and appropriate feedback such that each student moves progressively through the curriculum levels.

4. Teachers and students need to know the learning intentions and the criteria for student success for their lessons, know how well they are attaining these criteria for all students, and know where to go next in light of the gap between students' current knowledge and understanding and the success criteria of 'Where are you going?', 'How are you going?', and 'Where to next?'
5. Teachers need to move from the single idea to multiple ideas, and to relate and then extend these ideas such that learners construct, and reconstruct, knowledge and ideas. It is not the knowledge or ideas, but the learner's construction of this knowledge and ideas that is critical.
6. School leaders and teachers need to create schools, staffrooms, and classroom environments in which error is welcomed as a learning opportunity, in which discarding incorrect knowledge and understandings is welcomed, and in which teachers can feel safe to learn, re-learn, and explore knowledge and understanding.

While these six signposts do not use the term 'inquiry', in our view points 3 and 4 in particular are rarely attained by teaching in any other way. They also align particularly well with the new Junior Cycle specification for Science, and with our views of what we would like IBSE101 to help PTs develop. For this reason, while we do not see the terms 'good teaching' and 'inquiry' as interchangeable by any means, we acknowledge that conceptually they are very closely aligned.

1.4 Methods and Aims of the Study

This study has used a Design Based Research (DBR) approach to the development of a module designed to allow PTs to experience and reflect on inquiry activities. A DBR approach uses a local instruction theory that is implemented in a learning cycle (one version of which is what the PTs experienced while taking the module) and a research cycle (in which the researcher evaluates the impact of the learning cycle and the validity of the local instruction theory). The combination of a learning cycle and a research cycle is known as a design cycle. Figure 1.1 outlines this approach.

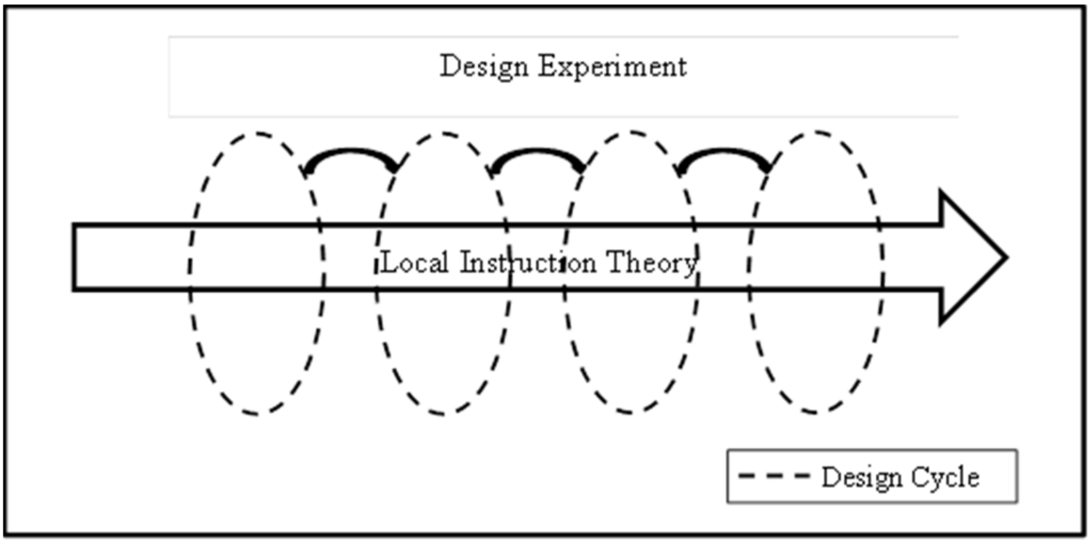

Figure 1.1 Basic outline of a Design Based Research process. Adapted from Gravemeijer and Cobb (2006).

By using a DBR approach, we could answer questions regarding PTs' learning, and use the answers to these questions to make refinements to subsequent learning and research cycles.

With each cycle with DBR, new perspectives are brought to bear on the problem. The thesis stays true to this principle, and introduces new perspectives whenever they become relevant to the research cycle.

There were some broad goals concerning both learning and research which helped to guide the direction this research took. The initial broad learning goals were

1. By participating in IBSE101, PTs would a) know what inquiry is, b) know what inquiry looks like and c) see how it can be done in the classroom; IBSE101 would aim to broaden PTs' Professional Vision, and extend their Apprenticeship of Observation;

2. PTs would get the opportunity to collaboratively solve problems as a group;
3. PTs would get the opportunity to reflect on inquiry activities.

In the course of the DBR process, a fourth learning goal was added:

4. PTs would learn unfamiliar content through inquiry.

The research aims for this project were to

1. Investigate the Professional Vision of Pre-service science Teachers as they participate in IBSE101;
2. Explore how studying PTs' PV can help inform changes to future iterations of IBSE101;
3. Investigate the characteristics of PTs' dialogue as they work though inquiry activities.

These research aims, combined with the goals of IBSE101, provide the basis for the overall research question, which runs through the overall Design Experiment:

> Q: How can the Professional Vision of PTs be elicited and broadened effectively within the module IBSE101?

Professional Vision (as defined and discussed in detail in Chapter 2) is a cultural process (Goodwin, 1994). There are many factors that might influence and also shape PTs' initial Professional Vision. In particular, PTs' Apprenticeship of Observation (Lortie, 1975) needs to be considered when investigating PTs' Professional Vision. With this in mind, as the Design Experiment progressed, the opportunity arose during Cycle 3 to investigate the Professional Vision of a group of PTs in the United States. This provided the opportunity to investigate a new group of PTs that had been educated outside of the Irish education system.

1.5 Research Timeline

The design experiment extended over 3 years, and included both learning cycles and research cycles. Figure 1.2 outlines where each cycle was situated in the timeline of the overall experiment. This figure will be revisited in subsequent chapters to elucidate its place in the context of design based research.

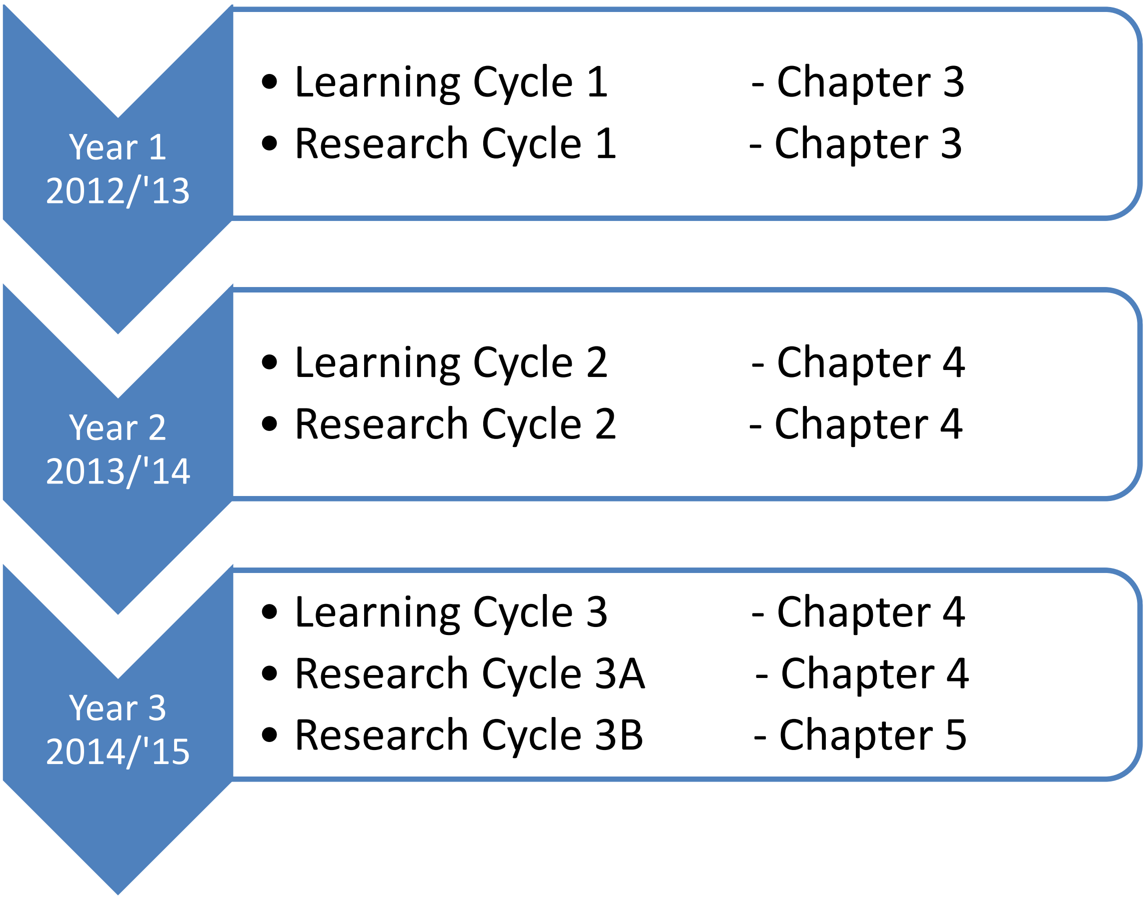

Figure 1.2 Timeline of Learning and Research Cycles.

Figure 1.2 outlines how the experiment progressed through the years. In Year 1, the first Learning and Research Cycles took place. Research Cycle 1 informed changes made to the local instructional theory, and consequently some changes were made to the Learning Cycle.

Year 2 turned out to be a very useful intermediate step towards a much more mature Year 3. Year 2 is therefore described at the start of Chapter 4, but primarily in terms of how it influenced the implementation of the Research and Learning Cycles of Year 3, which forms the most advanced Design Cycle attained in this research. In Year 3, the Research Cycle took two distinct paths, which we have termed 3A and 3B.

1.6 Thesis Layout

This thesis is presented in six chapters. The first chapter details the overall rationale and aims of the study. It also gives the timeline of the research as it progressed through the project. It outlines science education in an Irish context, including science teacher education.

Chapter 2 begins by looking at the nature of learning science, and the paradigms that underpin inquiry in the sense we use it – constructivism, and social constructivism in particular. It also outlines the Design Based Research methodology and the use of local instruction theory, learning cycles and research design cycles. The areas of Professional Vision and Apprenticeship of Observation are explored in detail. The overall aim of the chapter is to outline how the overall conceptual framework for the design experiment was built up, and how this contributed to the local instructional theory for IBSE101.

Chapter 3 describes Cycle 1 of the design experiment. IBSE is looked at in detail, and its alignment with the aims of IBSE101 is explored. During Cycle 1 PTs critiqued guided inquiry activities that they carried out in a series of workshops. Claims about the PTs' Professional Vision were made, and these informed changes implemented in the next Cycle.

Chapter 4 describes Cycle 2, where PTs analysed video footage of a class being taught using open inquiry in which the students explain a scientific phenomenon, having previously carried out the same activity as students. It also details Learning Cycle 3 and Research Cycle 3A, in which the PTs' highlighting and coding of teaching in the video footage is analysed. Chapter 5 describes Research Cycle 3B, in which the PTs' discourse during this activity is analysed. Chapter 6 explains how the three Cycles fit together, the results informed us about the ways PTs learn inquiry, and about the development of IBSE101. This chapter also looks at general conclusions drawn from the design experiment. It discusses possible future directions for IBSE101, along with outlining limitations of the study.

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Chapter 2 Theoretical Background

2.1 Introduction

This chapter describes the theoretical background of this study. The chapter begins by looking at the nature of constructivism and social constructivism. These ideas are core to IBSE (Minner, Levy, & Century, 2010). Following this the chapter discusses Professional Vision, and how the theory of Professional Vision provides a framework for the study, and how PTs' Apprenticeships of Observation can influence how they think about teaching is discussed. Finally, Design Based Research is described in detail, along with how it provided a methodology for the study.

2.2 The Nature of Constructivism

> "The core commitment of a constructivist position, that knowledge is not transmitted directly from one knower to another, but is actively built up by the learner, is shared by a wide range of different research traditions relating to science education." (Driver et al., 1994, p. 5)

The construction of meanings and knowledge can be looked at as a personal pursuit, or as a process of knowledge construction that comes about through learners being encultured in discipline-specific discourse (for an example in science, see Driver et al., 1994). In this process, knowledge is constructed when learners are engaged socially in a shared problem. Central to both of these views of learning is the importance of the learner's prior knowledge. Two cognitive theorists who were key to the understanding of how humans learn were Jean Piaget and Lev Vygotsky.

Piaget's (1896-1980) work focused on how learners develop mental structures in which knowledge fits. He called these schemes or schemata. There are three categories within these schemes: physical, social and logico-mathematical knowledge (Piaget, 1978).

According to Piaget, all of learning can be placed into one of these categories. New schemes are developed by modifying old schemes. This happens when a learner meets a situation where their existing schemes cannot explain new information. Piaget termed this process accommodation.

Piaget (1970) and his co-workers viewed learning primarily as change taking place in an individual. Their view of learning is sometimes called cognitive constructivism (Derry, 1996; Phillips, 1995). In their view the construction of meanings and informal theories that individuals develop about natural phenomena results from the personal interaction of learners with physical events in their lives. While acknowledging the value of collaborative work, their main focus is on how meaning is made by individuals, and how meaning depends on an individual's current knowledge scheme.

On the other hand, Vygotsky and co-workers argued that learning is primarily a social process. Bruner (1985), in an introduction to the work of Vygotsky, wrote that

> "The Vygotskian project [is] to find the manner in which aspirant members of a culture learn from their tutors, the vicars of their culture, how to understand the world. That world is a symbolic world in the sense that it consists of conceptually organized, rule bound belief systems about what exists, about how to get to goals, about what is to be valued. There is no way, none, in which a human being could possibly master that world without the aid and assistance of others for, in fact, that world is others." (p. 32).

This reflects the view that learning takes place by the social construction of knowledge. Driver et al. (1994) explain this in terms of 'meaning making':

> "a dialogic process involving persons-in-conversation, and learning is seen as the process by which individuals are introduced to a culture by more skilled members."

Chapter 3 discusses how these ideas apply to IBSE in general. The concept of 'meaning making' is closely related to our definition of 'sense-making' discussed in Chapter 5.

Table 2.1 (adapted from Hằng, Meijer, Bulte, & Pilot, 2015) outlines the features of a social constructivist approach to learning. Many of these features are used in the type of instruction employed in IBSE101, since we would like the PTs to employ them in their own classrooms. However, we acknowledge that indicators 4-i, 4-iii, and 5-i are not explicitly present in the activities.

Table 2.1 The features of social constructivism (from Hang, et al., 2015).

Feature	Indicator	
1. Learning is social	i.	Students work in whole class and/or
	ii.	Students work in small groups
	iii.	Students actively share ideas
2. Knowledge is experience-based	i.	Students' experiences are provoked
	ii.	Students elaborate interpretations of their experiences
	iii.	Students test interpretations of their experiences
3. Knowledge is constructed by learners	i.	Students are immersed in realistic learning situations
	ii.	Students elaborate interpretations of their experiences
	iii.	Students test interpretations of their experiences
	iv.	Students make meanings
4. All aspects of a person are connected	i.	Students' attitudes and emotions are revealed in learning
	ii.	Students take part in hands-on activities
	iii.	Students' values are employed and capitalised in learning
5. Learning communities should be inclusive and equitable	i.	Types of communities, e.g., families, organisations, institutions, etc., are involved to support students' learning
	ii.	Interaction of teacher-student and student-student should be equitable other than hierarchical

2.2.1 Criticisms of Constructivism

There have been some critics of constructivism (e.g. Matthews, 2002; Gil-Pérez et al., 2002). Matthews (2002) outlined how science teachers can encounter difficulties when teaching difficult and abstract topics. He also argued that a problem with constructivism is that curriculum developers can apply the word in different ways. They can see "constructivism as a theory of learning, philosophy, education, cognition, personal knowledge, scientific knowledge, educational ethics, politics and world view" (Matthews, 2002, p. 124). In an article reviewing some of the criticisms of constructivism, Gil-Pérez et al. (2002) warn of the dangers in the vague use of the term constructivism. This vagueness, they say, may make it possible for teachers and researchers to use the term to describe what they might always have done: "I explain concepts, and my pupils reconstruct them in their head" (p. 567). Gil-Pérez et al. also make the point that constructivist proposals should not be seen as a recipe or algorithm.

2.2.2 Constructivism, IBSE and the Design Experiment

Inquiry and IBSE are broad terms, and the various definitions of inquiry will be discussed in Chapter 3. However, all of these definitions are underpinned by the ideas of constructivism. In their review of inquiry professional development, Capps, Crawford, & Constas (2012) identified that by teaching science by inquiry, science can become more relevant to students when compared to other types of instruction. Inquiry teaching focuses on "active student knowledge construction in place of merely drill… and the memorisation of facts" (p. 295). Baviskar, Hartle & Whitney (2009) described the characteristics of constructivist teaching. These include eliciting prior knowledge, creating a cognitive dissonance, application of new knowledge with feedback, and reflection on learning.

For the design experiment described in this thesis, the definition of Linn, Davis & Bell (2004) is used. This describes IBSE as comprising of eight different elements. These are forming coherent arguments, debating with peers, distinguishing alternatives, planning investigations diagnosing problems, searching for information, researching conjectures and critiquing experiments. Within all of these elements it is possible to incorporate the features identified by Baviskar et al. (2009). Section 3.2 discusses this, and other definitions of inquiry in further detail.

2.3 Discourse in Science Education

As outlined in Table 2.1, a feature of social constructivism is that learning is not an individual process. Learning takes places socially, and among peers. Accordingly, discourse in the science classroom can take several forms. One of these, argumentation, is seen as a key goal of constructivist classrooms (Driver, Newton & Osbourne, 2000; Jiménez-Aleixandre, 2008; Jiménez-Aleixandre & Erduran, 2008). Duschl & Osborne (2002) emphasised that students should be given the opportunity to engage in argumentation in the classroom and to formulate explanations and evaluate evidence. Osborne, Erduran & Simon (2004) outline that incorporating argumentation into the science classroom has two functions. One is a heuristic function, which is to engage learners in the coordinaition of conceptual and epistemic goals. The other is to make students' scientific reasoning and thinking visible. This can enable formative assessment to be carried out by the teacher.

McDonald and Kelly (2012) suggested that while a strong focus on argumentation in student discourse is important, it may have limitations, especially in terms of

> "…supporting student learning, developiong students' understandings of the way scientists practice within their community, and supporting the development of productive norms and practices in communities of science learning " (p. 12)

McDonald & Kelly suggested that by focusing on scientific sense making, science educators and researchers can provide more support to science teaching and learning, along with science education research.

The importance of argumentation among PTs became more apparent as the Design Experiment progressed, and more emphasis was placed on discourse. Table 2.3 shows that for the final research cycle, a thought experiment was proposed that suggested a framework combining argumentation, sense making and transactivity would provide a way to analyse the type of discourse that takes place in the science classroom. Transactivity is seen as a bridge between argumentation and sense making, and Chapter 5 discusses how it was a key part of the analysis. Argumentation, sense-making and tranactivity are discussed in full in Chapter 5.

2.4 Professional Vision

Teacher education programs can provide an important baseline for teachers to acquire expert-like knowledge structures, through the integration of theoretical knowledge and practice (Hammerness, Darling-Hammond, & Bransford, 2005). In particular, identifying indicators of pre-service teachers' knowledge application in authentic situations as well as assessing their integrated teacher knowledge is of great importance (Cochran-Smith & Zeichner, 2009). One such indicator of pre-service teachers' knowledge of effective teaching and learning is their Professional Vision. Since being originally described by Goodwin (1994), the notion of Professional Vision has been applied to the area of teaching and teacher education by several researchers (e.g. van Es & Sherin, 2002; Gamoran Sherin & van Es, 2008).

Goodwin (1994) referred to Professional Vision as

> "socially organized ways of seeing and understanding events that are answerable to the distinctive interest of a particular social group." (p. 606)

When characterizing Professional Vision, Goodwin described it as a cultural practice consisting of three key activities: highlighting, coding, and creating material representations. Highlighting involves attending to particular professionally relevant aspects of a complex social activity in situ; coding pertains to the interpretation of what is highlighted, transforming it into categories that are relevant to the professional work. The use of material representations allows professionals to articulate their ways of seeing to others. In his paper, Goodwin gives examples of the Professional Vision of policemen as presented by the defense in the Rodney King trial, and that of archaeologists at an excavation. In both cases, Professional Vision requires knowing what is salient to understanding the professional activity. In the case of the example of archaeology, Goodwin outlines how the practices of highlighting, coding and material representations are used to help apprentice archeologists develop an expert's ability to see things on a site. Using this example, Goodwin explains that Professional Vision requires specialized knowledge to interpret and discuss a specific area of expertise. Goodwin uses the example of the Rodney King trial to show that a professional's way of seeing is socially recognized as both different and better than that of a non-expert.

The concept of Professional Vision has also been studied in the context of education research, and especially in the area of teacher learning. Teachers' Professional Vision is the ability to make sense of classroom interactions in meaningful ways (Sherin, 2001). The recognition that a classroom event is salient in itself requires significant understanding of teaching and its goals, as does the interpretation and subsequent response.

To date, a large proportion of research in the area of Professional Vision in teacher education has been in the context of mathematics education. Many of these studies have looked at pre-service teacher's ability to *notice* and *reason* about classroom activities, often while they are watching video footage of mathematical classroom practice. Noticing and reasoning are closely related to the ideas of highlighting and coding. van Es & Sherin (2002) described noticing as identifying what is important in a teaching situation. It also involves being able to make connections between specific events and broader principals of teaching and learning. Gamoran Sherin & van Es (2008) discussed that how a teacher reasons about events they notice is just as important as the act of noticing. Reasoning (sometimes called knowledge-based reasoning) describes a pre-service teacher's cognitive processing of classroom events, based on their knowledge of teaching (Stürmer, Könings, & Seidel, 2013; van Es & Sherin, 2002). Reasoning links the noticed situation to existing knowledge.

One common way in which pre-service teachers' Professional Vision has been studied is through the use of video clubs. Sherin & van Es (2005) investigated the noticing patterns of a group of middle-school mathematics teachers as they participated in a video club. They found that it was possible to change what the teachers noticed, and how they interpreted what they noticed. Gamoran Sherin & van Es (2008) also found that Professional Vision is a productive lens for investigating how teachers learn through the use of video. It is widely agreed that being able to identify and make sense of classroom events is one of the most important aspects of teacher expertise (van Es & Sherin, 2008; Borko, Koellner, Jacobs, & Seago, 2011; Santagata, Zannoni, & Stigler, 2007).

2.4.1 Apprenticeship of Observation

One way that pre-service teachers develop their understanding of teaching is based on their prior experiences as a student. Learning about teaching, and learning how to teach requires pre-service teachers to think about teaching in unfamiliar ways. These are usually different to experiences they had as a student. Lortie (1975) described this as the problem of the "apprenticeship of observation". Hammerness et al. (2005) explored the apprenticeship of observation in relation to helping pre-service teachers become "adaptive experts". They outline that:

> "Prospective teachers come to the classroom with preconceptions about how the world, and teaching, works. These preconceptions, developed in their

> “apprenticeships of observation,” condition what they learn. If their initial understanding is not engaged, they may fail to grasp the new concepts and information, or they may learn them for the purposes of a test but revert to their preconceptions outside the classroom” (p. 366)

Therefore it is important that teacher educators take the pre-conceptions that PTs may have about teaching into account when working with PTs. Levin, Hammer, & Coffey (2009) claimed that attention to student thinking should serve as a goal for teacher education. However, they suggest that this is difficult, owing to PTs’ apprenticeship of observation:

> “One major reason why novice teachers struggle to attend to student ideas and reasoning is their participation in the social and institutional systems of public schooling, which encourage framings of teaching in terms of classroom management and curricular coverage” (p. 152)

Levin et al. (2009) also suggested that a solution to the problem of the apprenticeship of observation is a greater focus on PTs paying attention to student thinking during their teacher education programmes.

Hammerness et al. (2005) explained that one positive of an apprenticeship of observation is that students have a large amount of experience of being in a classroom, and several PTs do draw experience from excellent teachers who taught them. However, they point out that these experiences can result in “serious misconceptions about teaching” (p. 367). Lortie (1975) explained that:

> Students do not receive invitations to watch the teacher’s performance through the wings; they are not privy to the teacher’s private intentions and personal reflections on classroom events. Students rarely participate in selecting goals, making preparations or post-mortem analysis. Thus they are not pressed to place the teacher’s actions in a pedagogically oriented framework” (p. 62).

PTs' preconceptions and misconceptions about teaching are important factors to take into account as they negotiate the process of initial teacher education. However, these can be used in a positive way to further PTs' understanding of teaching. Feiman-Nemser (2001) suggested that if teacher educators acknowledge that the beliefs pre-service teachers have about teaching act as filters for new learning, they can be given opportunities to "critically analyse their taken-for-granted often deeply entrenched beliefs so that these beliefs can be developed and amended" (p. 1017).

2.5 Design Based Research

2.5.1 Educational Design Research and Design Based Research

This study follows a Design Based Research (DBR) approach. Often referred to as educational design research, or design based experiments, DBR is an iterative process in which learning is studied in the context in which it happens. Thus DBR has a strong link with practice, and is suited to the aims of this research, which is to inform and bring about improvement in classroom practice.

Ann Brown (1992) was one of the first to use the term "design experiments". Design experiments were developed so that researchers could "carry out formative research to test and refine educational designs, based on principles derived from prior research" (Collins, Joseph, & Bielaczyc, 2004, p. 15). Brown (1992) expected that researchers would systematically adjust various aspects of the designed context so that these adjustments would be a type of experiment that would allow researchers to generate theory in naturalistic contexts (Barab & Squire, 2004). diSessa & Cobb (2004) claimed that design based studies should make significant contributions by addressing the gap between theory and practice. They also suggest that design research may offer new constructs for explaining educational phenomena. Gravemeijer & Cobb (2006) outlined a core philosophy of design experiments:

> "The underlying philosophy of design research is that you have to understand the innovative forms of education that you might want to bring about in order to be able to produce them." (p. 45).

This was the case with this study. One of the overall goals was to redevelop and enhance a module designed to a) introduce PTs to IBSE, and b) help them develop their Professional Vision of IBSE. However, in order to do this, it was first necessary to understand what their initial views of IBSE were, and to see how incremental changes to the module might change these.

McKenney & Reeves (2014) outlined the characteristics of Educational Design Research under a number of headings. Table 2.2 applies these headings to the present study.

Table 2.2 Educational Design Research overview, adapted from McKenney & Reeves (2014). Descriptions adapted to apply to this study.

Educational Design Research Overview	
Problem	IBSE has been identified as a way to help improve student achievement in second level science. Teachers must be supported to teach in this way. While modules have been designed to aid PTs, they still seem reluctant to teach in a way that supports IBSE.
Main Focus	Investigating how examining the PV of PTs can help inform changes to a module designed to support PTs in teaching through IBSE
Intervention Developed	A move from just analyses of IBSE activities to a combination of IBSE activities and video analysis
Knowledge Created	Alternative ways of looking at PV. Theory of how different elements of module contribute to PTs' PV. Can PTs' educational background also contribute? (US *v* Ireland)
Research Methods Used	Interviews Analysis of critiques Analysis of highlighting and coding data
Research Scope	Three year study 4 separate groups of PTs (3 IRL, 1 US) 1 of above groups studied over a 3 year period

Primary Practical Contribution	Information for teacher educators about how PTs' PV is shaped through a PCK module Contribution to theory on discourse and argumentation in teacher education

Before explaining how a DBR approach was used in this study, it is useful to look at its background, and how design experiments are used in educational research. The Design Based Research Collective (2003), a group of researchers founded to examine, improve and practice design based research methods in education tried to provide a comprehensive definition of DBR. They described DBR as an emerging paradigm for studying learning in context.

They proposed that good DBR is characterised by five features. The first of these is that the goals of designing learning environments and developing theories are "intertwined". Secondly, they shared the ideas of Cobb (2001) and Collins (1992) that research takes place through "continuous cycles of design, enactment, analysis and redesign". Thirdly, research must be sharable. It must lead to theories that have relevant implications for other practitioners. Fourth, the research must "account for how designs function in authentic settings". Finally, these accounts must rely on methods that "can document and connect processes of enactment to outcomes of interest".

The collective also point out that DBR goes further than just designing and testing interventions. When relating DBR to other methodologies, they indicated that they

> "do not claim that there is a single design-based research method, but the overarching, explicit concern in design-based research for using methods that link processes of enactment to outcomes has power to generate knowledge that directly applies to educational practice."

Key to all design based experiments are design cycles. Gravemeijer & Cobb (2006) discussed these cycles in the context of Realistic Mathematics Education (RME) in the Netherlands. They describe design experiments as a cyclical process of designing and redesigning instructional activities. The first step in this cyclical process is usually a "thought experiment" (Cobb, 2001). The purpose of a thought experiment is to envision how the proposed structural activities might be realised. According to Cobb (2001) a thought experiment "synthesizes the pertinent theories and models in a series of theoretical conjectures".

The outcomes of these theoretical conjectures are learning and research cycles. A learning trajectory is useful to describe the potential means and tools to support meaningful learning, while a research trajectory monitors the enactment of the learning trajectory. During the enactment of the instructional activities, and also through retrospective analysis, the students' participation and learning are analysed. On the basis of this analysis further decisions are made about the validity of the conjectures, and on possible revisions to the design.

Figure 2.1 shows the cyclical nature of Design Based Research, and how it comprises a series of thought and instructional experiments.

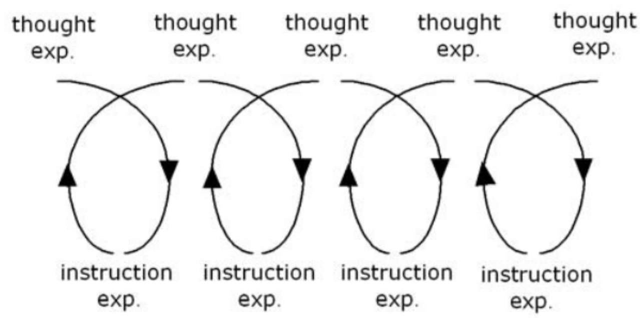

Figure 2.1 The cyclical nature of DBR (Gravemeijer & Cobb, 2006).

Both learning and research cycles take place sequentially, and students typically only experience one iteration of a cycle. It is therefore worthwhile to take a linear view of each the process of first designing a thought experiment and how this develops into a local instruction theory. We can look at one end of the thought experiment as being the instructional starting point, with the potential endpoints at the other end. What is developed then is the local instruction theory. This is shown in Figure 2.2. Such a local instruction theory consists of conjectures about a possible learning process, together with conjectures about possible means of supporting that learning process (Gravemeijer & Cobb, 2006).

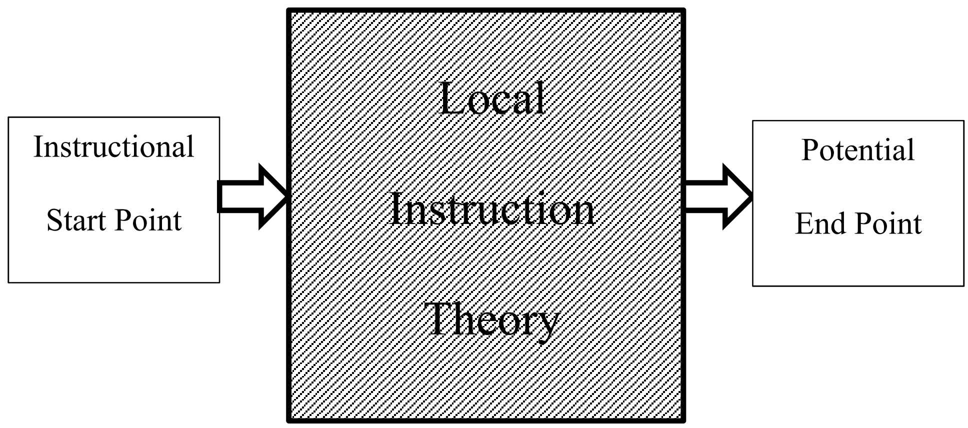

Figure 2.2 A linear view of a cycle of a thought experiment.

Over the course of the design experiment this local instruction theory is integrated through all of the cycles, as shown in Figure 2.3. Gravemeijer & Cobb (2006) explain how there is a reflexive relation between both the thought and instructional experiments, and the local instruction theory being developed, indicating how

> "On one hand, the conjectured local instruction theory guides the thought and instruction experiments, and on the other, the microcycles of design and analysis shape the local instruction theory". (p. 28)

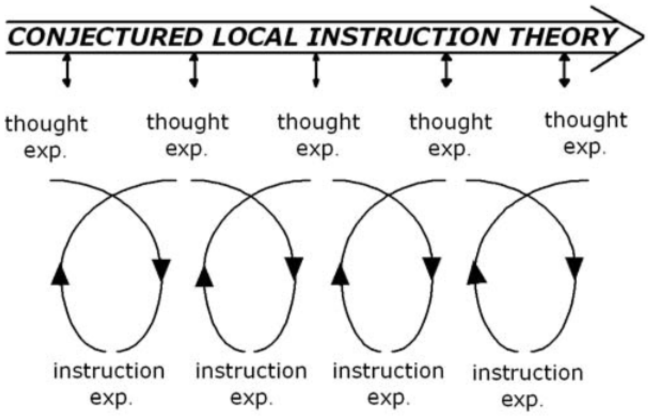

Figure 2.3 The nature of DBR including a conjectured local instruction theory (Gravemeijer & Cobb, 2006).

2.5.2 Issues with design based research

Although DBR is now seen as an established methodology in the learning sciences, there are still some calls to better define the method, and to increase its rigour. DBR defines itself as being practice-focused and as studying specific educational contexts and problems holistically. Not surprisingly, much of the criticism of DBR has focussed on it not being sufficiently theory-oriented, not isolating variables, and not providing context-free generalizations.

For example, Dede (2004) argued that DBR is a kind of “Swiss army knife” for scholars, capable of excelling at a wide range of purposes, but he worries about all-purpose designs. He identified a number of methodological issues: many variables are “deliberately & appropriately” not controlled; the intervention may evolve over time, and methodologies used may shift to fit the intervention; often large data sets, both qualitative and quantitative, are obtained which can pose problems; and there is a lack of standards to help researchers to decide if (or when) to abandon a design. He claimed that DBR is “under-conceptualised and over-methodologised”, which means that for many studies, the results reported are “common sense” for anybody with experience in educational settings, and that there is so much data that results can be inferred from only the first ~5% of data.

Kelly (2004) also raised methodological issues. His key criticism was the difficulty in developing studies “from a loose set of methods into a rigorous methodology” (p. 116). He also argued that a well-developed methodology will have a number of key characteristics, including argumentative grammar, problem demarcation, problem generalisation and meaningfulness. An example of this is a lack of rules guiding what data to gather in a DBR study. Further, another methodological issue is the complexity of the “cognitive ecology” of DBR research teams, contradictory tensions that can also lead to under-conceptualisation.

2.6 Implications for this research

This research has been informed by the theoretical considerations discussed above. We adopt a constructivist approach with a socio-constructivist flavour, both to teaching our PTs and how we would like our PTs to teach in the classroom. The strong emphasis on informing and reforming practice makes DBR an attractive and suitable research methodology for this work. In adopting this method, the criticisms of DBR have been taken to heart. Specifically, we have tried to limit data collection to what we deem to be essential, and we have taken care to thoroughly inform ourselves on other established methodologies and theoretical perspectives.

That said, we feel that we have stayed true to the spirit of DBR. With each of the three design cycles new perspectives have opened up, and different research methods and theoretical underpinnings have become relevant. We will discuss these as the need arises. Thus, in Chapter 3 we discuss IBSE and the inquiry spectrum with a focus on guided inquiry, the lens of Professional Vision, and claims generated about our PTs’

Professional Vision of IBSE. In Chapter 4, we look at open inquiry and video analysis and discuss literature in those areas, and in Chapter 5 we look at the literature on classroom discourse. The complexity of design based research has been noted in various studies, and it is something that we needed to take into consideration in this work.

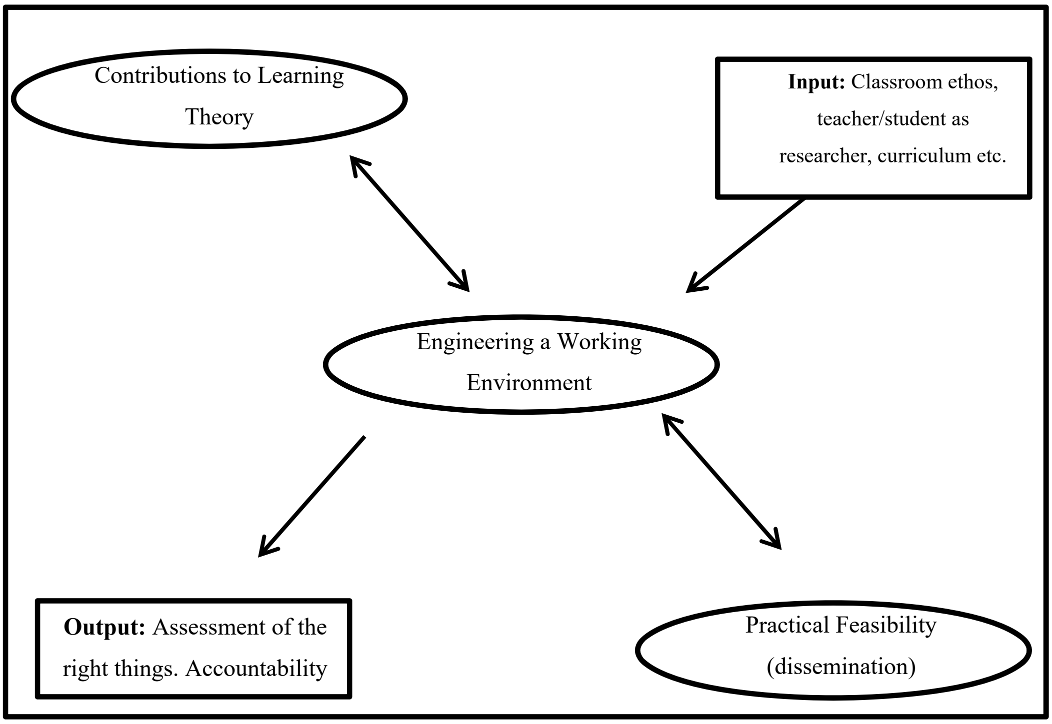

Figure 2.4 Complex features of the design experiment (redrawn from Brown, 1992).

Brown (1992) outlines the complex features in design experiments as depicted in Figure 2.4. This study also presents a complex environment in which the design based experiment is carried out. Similar problems to those outlined in Figure 2.4 were considered. Table 2.2 presents the solutions to some of these issues of complexity, but it is useful to describe them in this section also.

- Contribution to Learning Theory: We have deepened insight into our pre-service teachers' PV in a new way, namely by having them carry out and then critique inquiry-based activities ready for classroom use. We have also analysed the PTs' discourse while engaging in open inquiry using a new framework.
- Input: The PTs' learning environment closely mirrored what we would consider a classroom geared towards inquiry. All aspects of a social constructivist classroom listed in Table 2.1 were prominent throughout the module.
- Output: The outcomes of the intervention have been analyzed critically.

- Practical Feasibility: We have ensured that all activities the PTs engaged in could be used in the classrooms they would teach in with little or no alterations.

2.6.1 The Language of DBR

The overall study is referred to as the Design Based Experiment. However, in various DBR studies, different parts of the study are called by different names. Therefore, at this stage it is useful to describe the language that will be used throughout the rest of this thesis, and define its meaning. Within the Design Based experiment, there are three design cycles (referred to as Cycles 1, 2 and 3). Each design cycle is made up of a Research Cycle and a Learning Cycle. A Learning Cycle is what PTs see when they participate in IBSE101. These are informed by theory, and by results of other design cycles. A Research Cycle outlines the research that is carried out, using data obtained from a learning cycle. Both of these contribute to the local instruction theory, which is being refined as the Design Experiment progresses.

2.7 Overview of the Design Experiment

Table 2.3 provides an overview of the design experiment. The table outlines each cycle of the experiment in terms of both the research cycles and the learning cycles.

Table 2.3 Overview of the Design Experiment.

	Research Cycle		Learning Cycle	
	Thought Experiment	Research Questions	Cohort	LIT
Cycle 1 (2012/'13)	Engaging PTs in a series of mostly guided inquiry activities would help to broaden their Professional Vision and Apprenticeship of Observation	What are the practices that PTs highlight as constituting IBSE? How do they code these? What do the highlighting and coding tell us about how they learn to teach IBSE?	18 PTs (8F, 10M) working in 4 groups (4 or 5 per group)	• Experience IBSE • Reflect on IBSE
Cycle 2 (2013/'14)	PTs would experience open inquiry and also try and identify the important features of an open inquiry activity through the video analysis of an open inquiry activity being taught to a group of students. Results of this would inform future cycles	Cycle 2 worked on the development of research questions for Cycles 3A and 3B	13 PTs (8F, 5M) working in groups (2 or 3 per group)	• Experience IBSE • Reflect on IBSE • Vicarious experience of IBSE • Experience new content through IBSE
Cycle 3 (2014/'15)	Cycle 3A: Engaging PTs in a video analysis workshop would further elicit and broaden their Professional Vision Cycle 3B: The type of dialogue that takes place in the science classroom is transactive in nature, and combines both argumentative dialogue and sense-making dialogue.	Cycle 3A: What are the practices that PTs both highlight and code when watching IBSE activities? Are there similarities and differences between the practices of Irish and US PTs? Cycle 3B: Using a framework combining argumentation, sense-making and transactivity is it possible to characterise the discourse of PTs? Are there differences and similarities in episodes of discourse?	Cycle 3A: Ireland: 18 PTs (10F, 8M) US: 18 PTs (9F, 9M) Cycle 3B: 25 PTs (14F, 11M)	• Experience IBSE • Reflect on IBSE • Vicarious experience of IBSE • Experience new content through IBSE

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Chapter 3 Guided Inquiry - What do Pre Service Teachers 'See'?

3.1 Introduction

This chapter describes the first iteration of the design experiment. Before undertaking this design cycle a number of things needed to be considered, including a conceptual framework. The layout of the chapter will follow the process from the start to the end of the design cycle.

As described in Chapter 1, Inquiry Based Science Education (IBSE) is at the heart of the study. Given this, the chapter begins by discussing what inquiry is and the inquiry spectrum (Section 3.2) and how teachers learn to practice IBSE (Section 3.3). In early design cycles guided inquiry played a very prominent role, and therefore emphasis is placed on where guided inquiry fits both within this spectrum and as part of the overall study. Conceptualisation of the design cycle was informed by a review of other studies that looked at how teachers (both pre and in service) learned to teach by IBSE (Section 3.4). Following on from the conceptual framework, as with all cycles of the experiment, the first step was to propose a 'thought experiment'. From this thought experiment, research questions were developed for the first design cycle. The thought experiment is discussed in Section 3.5 in terms of the instructional starting point (i.e. the setting in which IBSE101 took place). The chapter then explains how claims were generated based on how PTs critiqued certain IBSE activities (Sections 3.6 and 3.7). The final section will discuss the approach in terms of Professional Vision, detailing what has emerged from the first design cycle (Section 3.8).

3.2 The Inquiry Spectrum & Guided Inquiry

Inquiry Based Science Education (IBSE) is a broad term, which has taken on many meanings. The word inquiry has been aligned to many ideas in science education literature. It can describe a scientific way of knowing (the work that scientists do), a way for students to learn science, an instructional approach, and even curriculum materials (Furtak, Seidel, Iverson, & Briggs, 2012).

Before looking at the different definitions of IBSE, it is useful to consider its theoretical background. IBSE is rooted in constructivism, which was discussed in Section 2.2. The idea of constructivism in science education focusses on the notion that learners should be engaged in answering authentic scientific questions (Capps, Crawford, & Constas, 2012, and references therein). Driver et al. (1994) argue that the core commitment of the constructivist position is that knowledge is not transmitted directly from one knower to another, but instead is actively built up by the learner. In their discussion on how scientific knowledge is constructed in the classroom, the learning of science is looked at in two different ways: learning science as an individual activity, and learning science as the social construction of knowledge. Capps, Crawford, & Constas (2012) argue that these scientific questions should also be relevant to students' lives.

The many definitions of IBSE reflect various views of constructivism, and encompass the thoughts of both Piaget and Vygotsky. Wheeler (2000) notes that the word inquiry is used as an elastic term that can be twisted to fit people's views. While this statement may have negative connotations, it can certainly be seen in the many research papers and reform documents that there is no agreed on, or single operational definition of inquiry. For example, the National Research Council (1996) defines scientific inquiry as

> "the diverse way in which scientists study the natural world and propose explanations based on evidence derived from their work."

There are many ways to characterise inquiry. One way is by looking at the degree of openness, on a three-to-five point scale. For example, Joseph Schwab (1960) introduced a three-level scale based on who poses questions, and who comes up with a method to solve the problem. At the first level, students discover a relationship unknown to them following a manual. At the second level, the teacher poses a question but the methods to find answers are left to the students. At the third level, students pose questions which they answer by their own methods.

He also proposed that science be taught in a way that reflected the way that modern science worked, encouraging teachers to use a laboratory with their students. He argues that in converting the school laboratory to inquiry it “leads” rather than “lags” instruction (Schwab, 1960). Schwab goes on to say that in doing this:

> “The laboratory ceases to be a place where statements already learned are merely illustrated and where perception of phenomena occurs within the restrictive structuring terms and concepts already laid down. It ceases, too, to be preoccupied with standardised techniques. It becomes, instead, a place where nature is seen more nearly in the raw and where things seen are used as occasions for the invention and the conduct of programs of inquiry. The laboratory manual which tells the student what to do and what to expect is replaced by more permissive and open material” (p. 187)

In more recent years, along the same lines as Schwab, different studies have identified different levels of inquiry. For example, the US National Research Council (NRC, 2000) talk about inquiry activities as encompassing a broad spectrum from teacher-directed structured inquiry, to open inquiry, which is student-directed. Banchi and Bell (2008) identify four levels: confirmation/structured/guided/open inquiry. The US National Research Council identify three: structured/guided/open (NRC, 2000); guided, bounded, and free inquiry (Wenning, 2005). Others simply use a dichotomy (guided/open or directed/open). Fradd & Lee (2001) devised a six point scale of inquiry based on the engagement of the student or the teacher, as outlined in Table 3.1. They used this table to illustrate how several aspects of inquiry (shown in the first row) could simultaneously be integrated. The case study also reported that learning to do inquiry became “a balance of teacher guidance and student initiative” (Fradd & Lee, 2001).

Table 3.1 Fradd & Lee's (2001) science inquiry matrix with transitions towards open inquiry. S=Students, T=Teacher.

Inquiry Level	Questioning	Planning	Implementing	Concluding		Reporting	Applying
			Carry out Plan/Record	Analyse Data	Draw Conclusion		
0	T	T	T	T	T	T	T
1	T	T	S/T	T	T	S	T
2	T	T	S	S/T	S/T	S	T
3	T	S/T	S	S	S	S	S
4	S/T	S	S	S	S	S	S
5	S	S	S	S	S	S	S

These scales have in common that at the closed end, inquiry is designed by the teacher and modelled as a carefully designed linear process that leads as many students as possible to appropriate pre-defined evidence-based conclusions, while at the open end students have a much greater say in the research questions, methods, and conclusions reached.

Open inquiry is the most complex form of inquiry (Sadeh & Zion, 2012). In open inquiry, the teacher “defines the knowledge framework in which inquiry is conducted, but the students formulate a variety of inquiry questions” (Sadeh & Zion, 2012 p. 32). It is argued that both open and guided inquiry are effective in developing inquiry skills and critical thinking. There is not always agreement among teachers or educators about what type of inquiry they prefer to use. Zion, Cohen, & Amir (2007) report that some teachers prefer using guided inquiry, while others prefer open inquiry. Olson & Loucks-Horsley (2000) report that it is important to link the type of inquiry used to the desired learning outcomes. This idea that the type of inquiry used will be different depending on the learning outcomes is one that needed to be taken into consideration when conceptualising the design cycle.

These classifications by themselves give little indication of what may take place in the classroom. Linn, Davis, & Bell's (2004) definition of inquiry allows different elements of inquiry to be enacted simultaneously in either an open or a guided setting. The definition of inquiry by Linn et al. (2004) reduces inquiry to seven different elements, namely: forming coherent arguments, debating with peers, diagnosing problems, searching for information, planning investigations, distinguishing alternatives, researching conjectures and critiquing experiments.

3.2.1 Inquiry and IBSE101

In this thesis, we will use a three point scale much like that of the NRC (2000) (the labels the NRC uses are structured, guided and open). We label the least open form of inquiry “structured”. In structured inquiry activities, students have almost no cognitive or procedural autonomy. The term will be used interchangeably with “cookbook” or “traditional” labs. Guided inquiry gives students little procedural autonomy but more cognitive autonomy; it is characterised by lots of what-if questions and linking various parts of the syllabus. Guided inquiry is seen as suited to classroom situations in which aiding students’ conceptual development and acquiring knowledge and understanding is emphasised. In what we call open inquiry we give students questions, problems, materials, and resources to investigate but also the freedom to pursue their own ideas.

We see open inquiry as ideally suited to classroom setting in which helping students develop their research skills takes centre stage.

3.3 Learning to Practice IBSE

It has been identified that teaching science using IBSE may improve students' learning of science. Therefore teachers should learn to teach by IBSE, but in doing so they face many challenges. Most pre-service teachers have very limited experience of IBSE, since almost all of their experience of school science has been through learning it as a student through teaching mostly by exposition. As discussed in Section 2.3.1, Lortie (1975) labels PTs' experiences as a student an apprenticeship of observation. He notes, in chapter 3 of his work "Schoolteacher", that:

> "There are ways in which being a student is like serving an apprenticeship in teaching; students have protracted face-to-face and consequential interactions with established teachers." (p. 61)

In practice this apprenticeship of observation means that beginning teachers may be reluctant to use practices that are different to the way that they were taught. It has been shown that personal history affects a person's identity, which also then affects their development as a teacher (Davis, Petish, & Smithey, 2006; Eick & Reed, 2002).

Much has been written on how prospective teachers learn to teach through inquiry, and of the challenges that they face. Crawford (2007) studied the knowledge and beliefs of PTs as they participated in a yearlong field experience in biology teaching. This study found that the teaching strategies of the PTs ranged over the entire inquiry spectrum. One of the reasons that the study found for this was that the personal beliefs that the PTs had about both science and teaching heavily influenced the PTs' propensity to teach science as inquiry. At the start of the school year, the participants in the study were enthusiastic about the prospect of designing inquiry based lessons. This waned as their teaching practice progressed, and the teachers in the study appeared to settle into a particular style. Crawford also discusses how this spectrum of practice has parallels with the work of Windschitl (2003). The latter study investigated how PTs' conceptions of inquiry were related to how they conduct and interpret their own inquiry. Windschitl was also interested in what conceptions were linked with PTs' use of inquiry in the classroom. While he found that the PTs' views of inquiry were related to how they conducted their own inquiry project, their use of inquiry in the classroom was mostly related to their own research experiences.

Lotter, Harwood, & Bonner (2007) also investigated how core teaching conceptions influenced teachers' use of inquiry practices. The three teachers involved in this study were practicing teachers, and their conceptions of inquiry based instructional practices were investigated while they undertook a professional development program. It was found that there were four core conceptions that influenced these teachers' use of inquiry in the classroom. These were their conceptions of science, the purpose of education, students, and effective teaching.

In an Irish context, a study by Lehane (2016) used a Pedagogical Content Knowledge (PCK) lens to investigate Irish PTs' orientations towards scientific inquiry, and found that they could enhance their orientations towards IBSE by working in a structured Professional Learning Community.

Looking at these studies it is clear that challenges do exist for PTs learning to practice IBSE. The fact that PTs' apprenticeship of observation is limited is a challenge. In developing a conceptual framework for Cycle 1, these challenges needed to be taken into consideration.

3.4 Conceptual Framework for the Design Cycle

3.4.1 Description of the Conceptual Framework for the First Design Cycle

Taking what we know about how PTs learn to teach science as a process of inquiry, and what factors influence this, we designed a module that allows PTs to also experience inquiry, and in doing so broaden their Professional Vision and Apprenticeship of Observation. The PTs' backgrounds therefore needed to be taken into consideration while developing a conceptual framework for the Design Cycle. We were aware that in some ways the first design cycle would also allow us to establish a baseline for students' attainment and apprenticeship of observation. We decided that the inquiry elements of debating with peers, forming coherent arguments and critiquing experiments were present in all of the PTs' activities. We note that these fit naturally under both guided and open inquiry, although they may be qualitatively different depending on the degree of guidance. Experiments would be critiqued both from a student's and a teacher's point of view.

3.4.2 The 'thought experiment' and potential endpoints

Previous research, discussed earlier in this chapter, has shown that it is possible for PTs to learn to develop an understanding of IBSE, and what it constitutes. However, according to Windschitl et al. (2012), PTs must be supported when they analyse their IBSE experiences in order to help them identify and understand the underlying purposes of the activities. It was envisaged that engaging PTs in a series of mostly guided inquiry activities would help to broaden their Professional Vision and Apprenticeship of Observation. We favoured guided inquiry initially because it is closer to the teaching they were used to. Banchi and Bell (2008) recommend that teachers start at the less open end of inquiry. It was envisaged that on completion of this redesigned module, PTs would have a greater propensity to teach through IBSE.

3.4.3 Research Questions for the Design Cycle

Leading on from the above, the following research questions were developed:

1.1 What are the practices that PTs highlight as constituting IBSE?

1.2 How do PTs code the purpose of the practices they highlight?

1.3 What do the highlighting and coding practices of PTs tell us about how they learn to teach IBSE, and how might these highlighting and coding practices inform future development cycles?

The first two questions related directly to the Professional Vision of the PTs. The outcomes of these questions feed into the third question, and also into the wider design experiment. Research Questions 1 and 2 are written in the language of Professional Vision (discussed in Section 2.3), as this was the lens used to examine the PTs' views.

The first question was asked to allow us to identify what features of IBSE PTs saw as important. The second question attempts to look more closely at the reasons why they highlight the things that they do. We wanted to understand why PTs felt particular traits of IBSE activities were important, and what they thought was the purpose of certain activities. The second question was designed to address this. Finally, since this study was just one cycle of an extended process, it was necessary to investigate how this cycle would inform future cycles of the experiment. Research Question 1.3 was developed to take this into account.

3.4.4 Qualitative Approach

Qualitative research is a broad approach to the study of social phenomena (Marshall & Rossman, 2006). The strengths of qualitative research derive "primarily from its inductive approach, its focus on specific situations or people, and its emphasis on words rather than numbers" (Maxwell, 2012, p. 17). Maxwell also identifies five purposes for which qualitative studies are suited. These include wanting to understand the meaning of events, situations and actions to participants of the study, understanding the context within which the participants act, identifying unanticipated phenomena and influences, understanding the process by which events and actions take place, and developing causal explanations. In this approach, claims are based on ideas of constructivism. The researcher, and their beliefs, values and background have a significant influence on the data collection, and the ways that data are interpreted (Denscombe, 2008).

3.5 Setting

3.5.1 Participants

During Design Cycle 1, there were 18 PTs (8 female, 10 male) participating in the study. All were Science Education students, in their second year of an undergraduate degree course which would qualify them to teach Science at lower secondary level, along with two subjects from physics, chemistry and mathematics at upper secondary level. The PTs were assigned to four random groups, and worked in either groups of four or five. The groups stayed unchanged for the duration of the IBSE101 module.

3.5.2 IBSE101

IBSE101, Physics Labs for Science Education is a compulsory module that all Science Education undergraduate students take in the first semester of their second year. At the time Design Cycle 1 took place, the module was taught for 6 weeks, whereupon students did their first teaching placement (and were out of university altogether) for three weeks, followed by a further three weeks in college which included IBSE101.

Prior to their teaching practice the PTs engaged in five different IBSE workshops, each lasting 3 hours. While broadening the PTs' experience and views of IBSE was the overall aim of the module (see Section 2.4), each individual workshop had a different focus aligned with these aims. The purpose of each workshop is summarised in Table 3.2.

The following sections report on the first five weeks of IBSE101. In the sixth week, they were interviewed (see Section 3.6.2) for 30 minutes and otherwise free to prepare for their school-based placement. In the final three weeks following their placement they were interviewed once again, reviewed their teaching practice, and designed inquiry-based lessons.

Table 3.2 Summary of weekly workshops.

Week	**1**	**2**	**3**	**4**	**5**
Content	Reflection of Light	Measurement and Units	Pushes & Pulls, Forces	Hooke's Law	Electric Conduction
Workshop Aim	Contrast open vs guided inquiry	Scaffolded approach to guidance	Constructing representations	Turning a mandatory Junior Certificate experiment into an inquiry activity	Exploring a concept before discovering its name

3.5.3 Detailed Description of Weekly Workshops

Week 1: Reflection of Light:

Two experimental activities investigating reflection of light in a plane mirror were designed for the PTs to contrast open inquiry and guided inquiry. The content was chosen because the experiment and its outcomes are understood by all PTs and are sufficiently simple to allow for meaningful open inquiry. In the open inquiry activity students were asked to investigate how light reflects from a plane mirror; they must describe in detail any measurements they make. No further instructions were given. In the guided inquiry activity version, students were asked to predict where a number of pre-drawn light beams will be reflected by a flat mirror; having done this, they are asked a number of what-if questions. The PTs carried out the open version of these activities before the guided version, and then were explicitly asked to discuss and compare both versions. A version of these activities is given in Appendix A.

Week 2: Measurement & Units

In Week 2 PTs were given a set of eight classes that had been used at the start of Year 1 (age 12) by an experienced teacher that employs a reduced scaffolding approach wherein students experience a range of activities that become more open-ended/less guided over the eight lessons. In this way the activities were designed to build on those of Week 1. In addition to having what-if questions throughout the guided activities, we introduce what we consider valuable teaching tools such as good use of web resources and homework questions that are formative assessment rather than drills. The classes involve among other things the topics of Units and Measurement, often considered boring when taught in an expository way, and density in a more open type of inquiry, which students often find difficult (see e.g Smith et al., 1997). The materials are given in Appendix A.

Week 3: Pushes & Pulls, Forces

This set of two guided inquiry tutorials focused on representations. In the first tutorial, students develop their own representation of forces to understand what needs to be represented. The tutorial thus aligns with the ideas of Hubber, Tytler, & Haslam (2010). In the second tutorial, the normative representation of forces was adopted and used to develop students' conceptual understanding of balanced forces and weight. The activities largely consist of questions based around thought experiments, and reinforce the use of what-if questions and homework as formative assessment embedded into a teaching and learning sequence. See Appendix A.

Week 4: Hooke's Law

One aim of the guided inquiry practical during week four was to show PTs how a mandatory experiment (i.e., one of 30 experiments Junior Cycle students must complete for certification) can be turned into an IBSE activity. As before, conceptual and what-if questions were included, and homework questions were designed as formative assessment. Students construct a spring balance by measuring the extension in a way they choose for different known masses. They evaluate its accuracy by graphical determination of the mass of an unknown object and comparing with a digital mass balance. Finally, in a follow-up tutorial students reason out the linear relationship between extension and force that is then called Hooke's Law. New elements include detailed interpretation of graphs and the principle of "concept before name", and planning a class based on a preceding experiment. See Appendix A.

Week 5: Electricity

PTs tested a hypothesis and planned an investigation to do so. The topic of electrical conduction was chosen as a vehicle for introducing the skills of planning an investigation and testing hypotheses because the content is typically poorly understood. In this guided activity PTs work with a basic electric circuit. At first they tested different materials in a series circuit to see how these affect the brightness of a bulb. Those that allowed the bulb to light were termed conductors, those that did not were termed insulators. In this way one good practice of IBSE, exploring a concept before naming it, was reintroduced. PTs were then asked to test the hypothesis that copper is a better conductor than nichrome wire. They were allowed to plan this investigation in any way they thought would work and were encouraged to think about making the test as fair as possible. In the final step, PTs were introduced to the term resistance. See Appendix A.

3.5.4 Local Instruction Theory for Cycle 1

Table 3.3 shows the two key components of the local instruction theory (LIT) for Cycle 1. At this stage of the design experiment, the local instruction theory included workshops in which PTs experienced and reflected on inquiry. It was designed to align with the broader aims of IBSE101 outlined in Section 1.4. During Cycle 1, PTs would get to experience inquiry through completion of each of the weekly activities. By critiquing these weekly activities, PTs got the opportunity to reflect on inquiry.

Table 3.3 Local Instructional Theory for Cycle 1.

LIT (PTs' experience)	Experience Inquiry	Reflect on Inquiry	New content through Inquiry	Vicarious Experience
Cycle 1	✓	✓		
Cycle 2				
Cycle 3				

3.6 From Critiques to Claims

3.6.1 Weekly Critiques

Weekly critiques were main source of data for Cycle 1. Each week, PTs were asked to write a critique of the IBSE activity in that week's workshop. One critique was produced per group. At the beginning of the IBSE101 module, PTs were given some guidelines on how to write these critiques. They were first asked to consider the physics content of the activity at university level, what physics content they would expect a Junior Cert student to know after completing the activity, and if they felt these students would have a full understanding of particular content (appropriate to the age group of the students) after completing the activity.

Each group was also asked to write global and question-by-question critiques of the activity. In the global critique they had to consider if the activity met the overall aims (in their eyes) of teaching physics as a process of inquiry, the sequencing, and if they felt any mandatory Junior Certificate experiments were covered. In the more detailed question-by-question critique the PTs needed to think about the purpose of each question and more particularly why it was asked at that particular stage of the activity. We wanted to try to get PTs to appreciate that each question that students are asked must have a purpose. They were also asked to point out any questions that they felt were unnecessary or unclear, and to provide an alternative. Finally they needed to consider any experimental skills that were addressed in the activity. These critiques along with interview transcripts made up the data that was analysed.

3.6.2 Interviews

Over the course of IBSE101, two sets of semi-structured interviews were conducted. These took place just before and just after the PTs undertook three weeks of teaching practice (also called school-based placement). In the pre teaching practice interview, early questions focused on how the PTs were taught science in both secondary school and at third level. These were followed by some questions specific to inquiry, such as:

In your modules at university there has been talk about inquiry science teaching.

- What is inquiry?
- How would you describe it to someone that is not in your module(s)?
- What are the key features?
- How do you “know it when you see it”?

A complete protocol is given in Appendix B. In the post teaching practice interview, PTs were asked questions that were specific to their experiences on their three week teaching practice placement. They were asked some general questions about the teaching in the school they were placed, and if they felt they had observed any IBSE lessons. They were then asked if they were able to teach any classes using IBSE, and if they felt their students were capable of teaching by inquiry. The protocols for the post teaching practice interviews are also included in Appendix B.

3.6.3 Generating Claims

In Section 3.7, claims about PTs’ views of IBSE will be presented. These claims were generated from analysing the weekly critiques and the interviews. The interview data was mainly used as a means of triangulation. Triangulation (the use of multiple sources of data) is one of the best known techniques for establishing credibility (Moschkovich & Brenner, 2000).

In order to generate these claims, each report was read and coded for the views of IBSE expressed in the critiques. An emergent coding process was used (Miles & Huberman, 1994). To give a better understanding of this process, and how it led to claims being generated, I will give a detailed description of how the process worked, using Week 1 as an example.

3.6.4 Arriving at Claims for Week 1

There were four people involved in the analysis. The first stage of the data analysis was the initial reading of the critiques. At this first stage, the aim was to highlight any quotes or passages that could be interesting in terms of analysis. This was guided by both the conceptual framework and the research questions for the cycle. As discussed in Section 3.2, the definition of inquiry that was used for this study was that of Linn, Davis & Bell (2004). This definition provided some guidance for each of the researchers when identifying passages of the critiques that were significant for analysis. The most obvious passages that were interesting were those that explicitly mentioned IBSE, but other passages that were noted included those that mentioned good teaching, or any references to students and how they might react to the material.

Each researcher brought their quotes to a meeting. This exchange of what PTs highlighted was followed by a more detailed reading of the critiques, and the generation of initial claims. A primary and secondary analyst was assigned to each critique. The job of the primary analyst was to perform second and third readings of the critiques, and to generate a summary document. This summary document contained some initial claims about PTs' views of IBSE, along with supporting quotes. An example of a summary statement, along with initial claims for Group D is shown in

Table 3.4. Each summary document contained between two and four initial claims.

Initial claims (Table 3.5) were generated per critique by each individual researcher.

Supporting quotes for these initial claims were based on the critiques from individual groups. The summary document was then reviewed by the secondary analyst, and claims were discussed. Following this, both readers edited the summary document, and claims were revised until agreement was reached. Revised claims were also generated per critique, and were based on all of the initial claims. At this stage of the analysis, we needed a common language for all of the researchers to use when generating claims. As a result many of the revised claims (Table 3.5) were described in metaphors. Table 3.5 shows the development of an initial claim, along with supporting quotes, followed by a revised claim.

Table 3.4 Example of a summary statement for Group D.

Summary Statement for Group D Week 1
They think that students will learn if they are 'tricked' into learning something. They mention a benefit in students "subconsciously" doing something (in this case creating a normal line). They talk about this part of the experiment tries to get students to apply theories of physics without realising they are doing it. Although they do seem to equate guided inquiry to traditional learning, they do mention that the questions will help the students to understand the material (especially the question where they subconsciously do something). It seems like they feel the main focus of the lab is to "correctly utilise their lab skills". Learning processes in the lab seems to be more important than understanding physics.

Table 3.5 Example of revising an initial claim.

Initial Claim & Supporting Quotes	Revised Claim & Supporting Quotes
The PTs see an open inquiry activity as a completely different type of activity to a structured inquiry, likening the structured activity more to a	Learning through inquiry is a scavenger hunt, and the reward at the end is the correct answer. Guided inquiry provides a map of the entire hunt so no one

traditional activity.	gets lost.
"…an enquiry technique that allows a student to think in a group and come up with a way to investigate in such a way which produces results." *[Group D Week 1]* "…is structured learning…a sheet of paper with questions and a procedure which will help us get through the experiment. The sheet starts off with easy questions and then proceeds to tougher questions." *[Group D Week 1]*	"This experiment gives enough examples for students to grasp the concepts of the 1st half of the experiment [referring to guided worksheet]" *[Group D Week 1]* "I think the structured layout as well as the inquiry-based methods have advantages and disadvantages. For students completely new to the topic, the temptation to play around with lasers and the mirror might distract them from experimenting to any great degree. The advantage of giving new students the structured based questions might be that it gives them a reference point to start, and for very young students they might panic and draw a blank if given equipment and told simply to "find out as much as they can". *[Group D week 1]*

After summary documents were revised for all groups, more general claims for each group were generated. Summary claims were less fine grained than the initial and revised claims. They were generated at a 'per week' level, instead of a 'per critique' level. They were also based on the collection of all revised claims, not just on the claims representing one individual group. At this stage of the analysis, as a team of researchers we were becoming more familiar with the data. The claims were mostly described in evolving metaphors. When agreement was reached between all four researchers, the initial fourteen claims for Week 1 were reduced to four main summary claims. These are show in Table 3.6.

Table 3.6 Main summary claims for all critiques in Week 1.

Claim 1	Claim 2	Claim 3	Claim 4 (Counter Claim)
Teaching is like a jigsaw puzzle where the teacher arranges the pieces in a way that students can put them together themselves without making mistakes. [Every day is its own complete jigsaw puzzle.]	Knowledge is a static entity, so first you must know something, then understand it, then apply/use it. Knowing is thus a prerequisite and the most important.	Learning through inquiry is a scavenger hunt, and the reward at the end is the correct answer and the correct procedure. Guided inquiry provides a map of the entire hunt so no one gets lost.	Counter claim: open is really good and guided is lock step and does not require much thinking.

Finally, after further discussions between researchers, three main claims, along with supportive quotes were arrived at for Week 1. These are shown in Table 3.7. These claims were based on all of the summary claims. Like the summary claims, they were generated on a 'per week' basis. In order to answer the research questions, the claims needed to be presented using an analytical description. For this reason the final claims were not described in metaphors.

This process was repeated for subsequent weeks. Regular face to face meetings between researchers helped to ensure reliability and consistency when generating claims. In Section 3.7 the main claims for each week are presented along with supporting quotes for all claims.

Table 3.7 Three final claims for Week 1.

Claim 1	Claim 2	Claim 3
PTs identify and differentiate between three kinds of practices	PTs see engaging in the Junior Cert mandatory experiments via	PTs see engaging in mandatory experiments via open inquiry as

within science teaching: reading from a book, guided inquiry (anything led or structured by the teacher) and open inquiry (where students design their own experiments). It appears that the PTs feel they must choose one form of teaching over the other; they don't seem to think that each practice may suit a different purpose.	open inquiry as events that will help students with remembering - for better or for worse.	enjoyable (affective)

3.7 Analysis

Here, claims about PTs' views of IBSE are presented on a week-by-week basis. These final claims were all generated using the method detailed in Section 3.6. They are presented with supporting quotes, and a short discussion of each claim.

For consistency, each claim was presented with either 2 or 3 supporting quotes. In order for a claim to be included as a final claim, it was ensured there were at least two quotes supporting the claim. Table 3.8 shows the total number of quotes that emerged from the initial analysis for each week's critiques. Through the process described in Section 3.6, final claims were generated and representative supporting quotes were selected from the collection of quotes from each week.

Table 3.8 Total number of quotes per week.

Week	1	2	3	4	5
No. of Quotes	56	77	70	47	53

3.7.1 Week 1: Reflection of Light

Based on the students' critiques of the experiment, we were able to extract three claims regarding their views of both science teaching in general, and their views of IBSE within these.

Claim 1.1: *PTs identify and differentiate between three kinds of practices within science teaching: reading from a book, guided inquiry (anything led or structures by the teacher) and open inquiry (where students design their own experiments). It appears that the PTs feel they must choose one form of teaching over the other; they don't seem to think that each practice may suite a different purpose.*

Two groups, for example seemed to rank the forms of teaching in terms of higher order thinking, or enjoyment:

> "The open approach calls for higher order thinking by the students, where the guided approach is as the name suggests, more guided with questions for the students to answer thus not encouraging as much higher order thinking by the students." *[Group D Week 1]*

> "Guided learning is not particularly enjoyable, though doing things is always more enjoyable than simply reading them from the students point of view." *[Group B Week 1]*

On the other hand, a different group discussed the advantages of guided inquiry over open inquiry:

> "The advantage of giving new students the structured based questions might be that it gives them a reference point to start, and for very young students they might panic and draw a blank if given equipment and topld simply to 'find out as much as they can'." *[Group C Week 1]*

Claim 1.2: *PTs see engaging in the Junior Cert mandatory experiments via open inquiry as events that will help students with remembering - whether this is for better or worse.*

One group of PTs was concerned that open inquiry (referred to as "the first experiment" in the quote below) could lead students drawing the wrong conclusions, and that they will remember these wrong conclusions:

> "Also, in the first experiment, the lack of instruction could lead to students coming up with wrong and misguided conclusions because of simple errors made when measuring the norm or angles, or simply from them not taking measurements at all." *[Group B Week 1]*

Another group felt that open inquiry would promote students remembering the outcomes, as they would engage with the experiments at a deeper level:

> "Using the guided approach, the mandatory experiment is covered and the students will learn from it, however I feel that the knowledge won't be retained because of a lack of a need for thinking on their part." *[Group B Week 1]*
>
> "An open lesson plan gives the room for a broader range of thinking with a possible result of greater understanding at the end." *[Group B Week 1]*

Claim 1.3: *PTs see engaging in mandatory experiments via open inquiry as enjoyable.*

Some groups paid attention to the affective aspect of experiments, talking about how enjoyable different methods may be.

> "In using the open approach, there is no specific order in which students need to conduct the experiment. Most students will enjoy this more so than the structured approach as they will have more freedom to discover the material in a way that is logical to them." *[Group B Week 1]*
>
> "We enjoyed the open inquiry as it was a relaxed environment, and we could allow the students to take their own initiative while designing the experiment."*[Group A Week 1]*

During the first week of IBSE101, PTs held the view that open inquiry was good for students as it would help them to better remember the content they needed to learn, partly because they would enjoy the opportunity to explore; however, they also felt that engaging students in open inquiry could be somewhat risky. Students could end up remembering incorrect ideas if they are allowed to proceed through an experiment without guidance. This showed a tension in their thinking - that open inquiry is "better" because it is more enjoyable than guided versions of the same experiment, but "worse" in that it could lead to students learning incorrect scientific content. PTs appeared to consider surface features rather than thinking deeply about the principles that underpin IBSE. For example, they seemed to equate guided inquiry to the use of worksheets designed to ask students specific questions that would guide them through an activity.

3.7.2 Week 2: Measurement and Units

Based on analysis of PTs' critiques from this activity, we were able to generate one new claim about PTs' conceptions of IBSE.

Claim 2.1: *PTs feel the purpose of eliciting students' ideas is to identify wrong views/ideas, and it is the teacher's job to navigate students through an activity, or set of activities so that all students follow the same path to a correct answer.*

> "[Eliciting students initial ideas] is a very useful tool to introduce in your class as not only are you teaching the material, you are also teaching that it is ok to be incorrect as learning from your mistakes is the best way to retain new information." *[Group A Week 2]*

> "The student carves out his own conceptions and as stated in the global discussion it does not matter whether this is right or wrong, once [the teacher] can rectify afterwards." *[Group B Week 2]*

PTs see the role of the teacher as one which is very specific. However, this view of the teacher as someone who is there to guide all students along the same path can be problematic. An example of this can be seen in the following quote from Group A, in which they seem to be unaware that there is a conflict between "keeping students along the right lines" and "encourage[ing] to think for themselves":

> "By keeping students along the right lines during an activity, it ensures that they stay motivated at all times but encourages them to think for themselves in order to find out the answer to the question." *[Group A Week 2]*

During Week 2, the focus of the PTs shifts from comparing open and guided inquiry to talking about students coming to the "correct" answers, even though in our design it was intended to build on Week 1. The practice of eliciting students' ideas is not talked about in terms of the benefits it can provide, i.e. student ideas being a productive starting place for discussion and building normative understanding. Instead they see the practice as a means for the teacher to correct wrong ideas or misconceptions. They also appear to view progression of student learning as a linear process. In their view, not only should students end up with the right answer at the end of a class, but there should also be little straying from the 'right' path while students are doing any part of the tutorial. This workshop took place only one week after Week 1, but the way that PTs talked about guided inquiry changed quite significantly. One reason for this is probably the degree of guidance in the activity. The PTs pay attention to the level of detail required by students in their reasoning. In fact, this concerned the PTs. This is in contrast to Week 1 where they showed some concern for the bigger picture.

3.7.3 Week 3: Pushes and Pulls

For the third workshop, two claims were generated about PTs' views of IBSE. Similar to Week 2, the themes of correct knowledge and the role of the teacher feature in the claims for Week 3.

Claim 3.1: *PTs see teaching as conveying correct knowledge and correct representation of that knowledge. Eliciting students' ideas at the beginning of a tutorial can help achieve that aim, but wrong ideas must be corrected quickly.*

> "I think it is good that the students start with their own view of forces and afterwards the convention is introduced. However, I do think that the convention is introduced too late into the topic. It would work more effectively if the convention was introduced at this point, before the class ends." *[Group A Week 3]*

PTs also address the idea of students retaining wrong information in this week's workshop. They are concerned about the possibility that students may develop incorrect ideas, and that they may retain these ideas if they are not addressed straight away.

> “This is a crucial point in the tutorial and in the understanding off physics, therefore it may be necessary for students to consult with another group or with the teacher.” *[Group B Week 3]*

As discussed in the Section 2.6, discussing representations in physics was the main aim of the workshop in Week 3, so unsurprisingly this was mentioned by many of the groups. However, the main focus of the PTs was on students’ knowledge of normative representations. They did not appear to see the benefits in students going through the process of developing a representation (e.g., the discussion itself, and identifying what needs to be represented and what does not); instead they felt that students should be quickly made aware of the normative representation.

> “The main purpose here is simply to show them that the force something exerts on another body can be drawn as an arrow. In order to explain why two arrows from the boy’s hand is not preferable, the teacher could mention how since there is only one boy, there must only be one arrow.” *[Group C Week 3]*

Claim 3.2: *PTs define the teachers’ role in terms of making things easier for the students. This can be done by not allowing students to go too far down the wrong path, or by making the links between parts of an experiment or activity conceptually simple.*

PTs’ overall idea seems to be that students must gradually build up their knowledge of a particular topic, with the teacher providing some hints, or guidance, along the way. They feel that the goal for students must be to arrive at the correct answer, and that information should be gradually given to the students. Teachers must “lead students in gently”, either by starting with concepts that are less challenging for the students, or by breaking concepts into manageable chunks and sequencing them.

> “It [the sequencing] leads the students in gently to give them the idea that a force applied to an object has an effect on that object.” *[Group B Week 3]*

> "The question introduces the idea in a nice way, in that it gets the students to first draw the force that would be most intuitive to them (Gravity)" *[Group B Week 3]*

> "The teacher should work this topic [how to conventionally draw the arrows] into the class at an earlier stage to avoid confusion." *[Group A Week 4]*

While critiquing the workshop from Week 3, PTs continued to focus on guiding students to the correct answers, via the correct path. However, this week also saw PTs introduce new criteria to their notions of good teaching - correct representations. From this workshop, they extracted that the representations that students make of physical phenomena such as forces must be correct as early as possible in the process. They feel that if students do not use normative representation, they will get confused or frustrated when the normative version is introduced. As an extension of this idea, they also start to talk about the ideas of scaffolding. However, any scaffolding provided, especially scaffolding in the form of questions on a worksheet, must be designed so that students must never have too much of a conceptual gap to bridge from one question to the next. They feel that if gaps like this exist, these are the only opportunities for students to get things wrong, go off track or get frustrated.

3.7.4 Week 4: Hooke's Law

Two claims were generated following on from the PTs' critique of the Hooke's Law activity.

Claim 4.1: *PTs think the goal of the tutorial is to learn facts, and the route to doing this is by experimentation.*

While critiquing these investigations, the PTs indicated that their purpose was about knowing specific pieces of science content. This was stated quite explicitly by one group:

> “The purpose of the experiment was to further the students knowledge of forces” *[Group D Week 4]*

Claim 4.2: *The PTs are concerned about confusion among students if minor variations are allowed within a guided activity. They hint at what they think is the purpose of a good class - every student remembering the same correct answer arrived at by the same correct procedure.*

> “The only problem that arises is that some groups will measure their springs at different points and wile all the extensions should be the same the lengths that the students get will be different” *[Group C Week 4]*
>
> “The only problem that may arise is that different students will measure from different points on the spring, but the underlying physics is that all the students will obtain the same extension” *[Group A Week 4]*

As well as focusing on the procedure of the lab, and consistency of measurement, PTs also focus on the actual equipment that students use, and making sure they know their names.

> “This question is asking the students to reflect on how they used the equipment in the experiment, this will encourage students to be more observant when using equipment and also to remember the names of the equipment instead of calling it the “thingy, doofer, boingy thing” etc.” *[Group D Week 4]*

As a suggested extra question, one group proposed:

> “What is the purpose of the pointer on the spring? While this might seem like a very simple question, it is essential for the students to identify the purpose of the pointer and to use it in their experiment to record accurate measurements or they could end up with very different extensions for the same mass” *[Group D Week 4]*

3.7.5 Week 5: Electric Conduction

For the final workshop, we were able to generate one claim arising from the PTs’ critique of the activity.

Claim 5.1: *The PTs feel that new terms and definitions are the most important things to take from the activity, and that great care should be taken when introducing these - perhaps inquiry is not up to the task?*

After 5 weeks of workshops consisting of IBSE activities, it is evident that some PTs still have some difficulty in seeing the main purpose of activities in terms of an interpretation of IBSE. While this weeks' activity introduces the idea of designing an experiment, there is little talk of the benefits or values of this process in the critiques.

> "Before this question the students are introduced to two new words which are very relevant to this experiment. The students will need to relate to the definitions of these new words in order to complete this question successfully."*[Group A Week 5]*

The focus of the PTs remains on facts, labels, procedures, and ways to correctly remember them.

> "We think the teacher should give a verbal explanation here and also ask plenty of questions to make sure that everyone in the class understands the new terms"*[Group C Week 5]*

PTs don't seem to consider that their students may have ideas that exist before these terms are introduced. They feel that only things that are correct should be discussed in class.

3.7.6 Interviews

Two sets of interviews were also conducted with PTs during the course of IBSE101. One of these was held before PTs went on three weeks of teaching practice, with the other held when they came back. It was only possible to generate claims using data from the first interview (pre teaching practice interview). It was hoped that that the second set of interviews would also provide some insight into the PTs' views of IBSE, however this turned out not to be the case. The interviews were mainly used as triangulation data. The main purpose of the pre teaching practice interviews was to give a more in depth ideas of what the PTs' views of teaching and IBSE after five weeks of workshops. Some of the claims that were generated from the critiques were supported by the interview data, while some other interesting findings were noted.

Claim I.1: *PTs believe that inquiry comprises small fun practical activities that are interspersed in otherwise standard classes.*

The idea that inquiry is seen as an 'add on' had not emerged from analysis of PTs' critiques; however it did emerge during triangulation analysis. It emerged after PTs were asked about their own experiences of being taught science

> "And those classes were usually a little more inquiry based just because there were more practicals and stuff. Not even long practicals, but just like here this is, em, glucose, what does it taste like, tastes like sugar, glucose is energy, sugar is energy and just little small things like that. And the other very one was very like, theory based and that was my second year" *[Group C Audio 00:04:30]*

Claim I.2: *The PTs make a distinct separation between practicals and theory. When practicals are not preceded by theory they define this as inquiry.*

This distinction can be seen as an indicator of some change having taken place, although still at quite a superficial level. However there are still signs that at least one surface level feature of inquiry has been introduced into their model of teaching. The views expressed in this claim are consistent with the ideas of concept before name. The view implicitly places a value on exploration, as long as IBSE is seen by the students as a viable approach. During the interview, one group felt that they were taught about force only from the definition. They appear to see their view of inquiry - that is doing the practical before the theory - as an improvement on this.

> "The forces one, where that was introduced with the bluetak, I thought that was really good, because the way that we were taught forces, was a force is something. Like you are given the definition. And this way you were working towards finding out what the definition was for yourself, so I think that is better" *[Group A Audio 00:16:59]*

> "In the more old fashioned based learning the definition is given at the start, in more inquiry based learning the definition is given at the end" *[Group B Video 00:21:35]*

Group D explicitly talk about the structure or sequencing of a topic, making a distinction between "labs" and "theory".

> "I think the labs would be more useful at the start of the topic, before you actually do the theory because then they kind of know it and they're still able to ask questions and then they're doing the theory and they're like oh that's…, I learnt that already, I could have figured that out myself" *[Group D Video 00:19:24]*

The interviews were also useful in that they broadly confirmed some of the earlier claims that were generated from analysis of the critiques. During the interviews, some groups talked about how they believed students needed to be guided towards the correct answer during an investigation, or given the correct answer after an investigation.

> "I like the way, sorry, they come up with their own models, you know they kind of have their own ideas and you kind of ask questions and lead them towards the actual proper models, they might be right but you have to make sure they are right." *[Group B Video 00:19:20]*

Another group indicates that a purpose of IBSE is that it gives an allowance for students to be wrong.

> "You're giving them the tools to be able to come up with theories or concepts or definitions themselves and help in guiding them in the right path if they start to stray at any point." *[Group D Video 00:15:25]*

3.8 Professional Vision - What Emerged from this Cycle

One of the main aspects of professional vision is highlighting. Highlighting identifies what are the aspects of IBSE activities that PTs think are important. As mentioned earlier, Professional Vision is usually examined in the context of novice learners examining professionals carrying out activities in the field. In this study, PTs were instead engaged in IBSE practices, and then highlighted the aspects of these activities and practices that they felt were important.

After the claims about PTs' views of IBSE were generated, it was found that they characterised teaching in three broad ways: rote learning, guided inquiry and open inquiry. By rote learning, they meant that either students read from a book, or listen to a teacher reading. They also consider taking notes from slides etc. as a version of this. A level 'above' this type of teaching is what they classify as 'guided inquiry'. PTs use this as a broad term, but it involves students being engaged in some sort of activity, which is usually practical. Lastly, PTs see open inquiry as a step above this again.

PTs also identified questioning during practicals as something that was important. However, they raise concerns that questions must not be too hard. In week four, one group discusses an idea of scaffolding. In order for students to be able to answer questions, steps must be "just right". They label this as "hardness", describing that "questions would be too hard for students to answer and should be made more clear so they will not get confused" [Group D Week 4]. Throughout the module, PTs highlighted the level of guidance, sequencing of questions and correctness as criteria for deciding on the purpose of IBSE activities. Figure 3.1 below shows a graphical representation of this.

Categories:	Rote Learning	Guided Learning	Open Learning
Characteristics:	Reading	Actively engaged in some process (engaged means anything other than reading)	Students design their own experiments. However the focus here is on procedural knowledge.

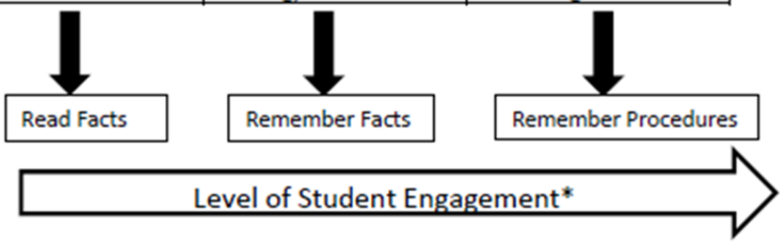

Figure 3.1 Summary of the views of PTs

Along with looking at what aspects of IBSE activities that PTs highlight as important, key to the design experiment is trying to understand why they feel that these are important, or in the language of professional vision, coding. During the third week of workshops, PTs viewed scientific representations as something that students should learn as fact. They did not discuss how it could be valuable to allow students to initially form their own representations. One concern is that activities should not leave students confused. When highlighting the purposes of IBSE activities, PTs continually talked about hardness and confusion. They also viewed the purpose of practical activities as being able to remember a procedure and materials, followed by remembering the 'correct' outcome of the experiment. PTs feel that eliciting students' ideas is only a strategy to hear any misconceptions that students may have regarding a particular topic, so that they can then correct them. They don't see this as a practice where students are creating initial models of what is being studied (Windschitl, 2004).

In Week 5, PTs also identified with the theme of correctness. In the critiques for the Electric Conduction workshop, PTs questioned if the correct answer (what they call theory) should be given to students before or after they have completed an activity. One of the concerns is that allowing students to perform an experiment without knowing correct terms could lead to students to leave with incorrect ideas, which will then have to be corrected.

It is clear that in these early stages of developing an understanding of IBSE, the PTs' notions were still quite plastic. It is impossible to say to what extent the timeline of the changes in their ideas are influenced by our sequencing of the activities. It is therefore safest to consider the difference between the start and end points of these five workshops.

One of the aims of this cycle was to use PTs' highlighting and coding practices to inform any future design cycles. One conclusion is that it is clear that both the Junior and Leaving Certificate examinations still strongly influence PTs' practice. This is evident in their tendency to focus on facts and procedures. As discussed in Chapter 1, both the Junior and Leaving Certificate have a huge pace in Irish school culture. The Apprenticeship of Observation PTs have been exposed to therefore will have been one where these exams have had prominence.

For future cycles of the workshops and indeed the module, this is something that would have to be considered. While it was felt that the overall structure of the workshops was useful, and did bring up several useful discussions with PTs, it would be useful to bring in some new aspects that might help to bring the focus of PTs away from facts and procedures. Each weekly workshop in the present cycle was designed to engage PTs in IBSE activities.

While the weekly activities were designed to be used or adapted for use in Junior Cycle classrooms, PTs were not actually seeing IBSE being used in the classroom. So PTs may have left the workshops thinking that, since they have not "really" been taught in a way like this, IBSE would not be practical to use while in the classroom. Chapter 3 reports on PTs' highlighting and coding practices of an IBSE activity that actually took place in the classroom. This was done through PTs engaging in video analysis of an IBSE activity taking place.

PTs' focus on content also raised questions about how they might critique IBSE activities that focus on content that they are not familiar with. Therefore this is something that was also considered including in future design cycles.

3.9 References

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Chapter 4 Open Inquiry - Using Video Analysis

4.1 Introduction

This chapter reports on Design Cycles 2 and 3. This work extends what was reported on in Chapter 3. As with Cycle 1, a number of things needed to be considered before carrying out this iteration of the experiment. Similar to Chapter 3, the layout of this chapter follows the process of the design cycle.

Cycle 2 comprises an 'intermediate' year in the timeline (outlined in Section 1.5) where some changes to both the learning and research cycles were trialled. These changes involved using more open forms of inquiry and video analysis of IBSE classes. In Section 4.2 open inquiry is discussed in the context of the IBSE101 module. This builds on the literature that was reviewed in Chapters 2 and 3. The use of video analysis in teacher education, and science teacher education is then discussed in depth in Section 4.3. Cycle 2 itself is reported on in Section 4.4.

For Cycle 3, in line with the process of Design Based Research, we needed to develop a conceptual framework. Conceptualisation of the design cycle was informed by a review of other studies looking at how PTs learn about open inquiry, and also how they learn through the use of video analysis. Results from Cycles 1 and 2 also influenced the conceptual framework.

After reviewing this literature, the conceptual framework for Cycle 3 is described. Firstly the outcomes from Cycle 1 were used to inform the development of this cycle. This included a trial of two workshops for inclusion in the second cycle. These are discussed, along with details of how these informed the development of Cycle 3. The next sections of the chapter focus on the thought experiment for Cycle 3, along with the research questions.

The sections following this introduce the themes that emerged from the PTs' highlighted clips, detailing how PTs highlighted instances of student ideas and good teaching. The final sections of the chapter then look at how this cycle informed the overall development of the design experiment, and what further insights were revealed about PTs' professional vision, and their views of IBSE.

4.2 Open Inquiry

As discussed in Chapter 3, it is widely recognised that inquiry instruction can take many forms, and exists at different points of an "inquiry spectrum" of openness. In our definition of the inquiry spectrum, teacher-led activities lie at the guided end of this spectrum, while student-directed activities lie at the open end. Until this point in the design experiment, the IBSE101 module had mostly included guided inquiry activities, designed to be mostly teacher led. However, in light of the results reported in Chapter 3, it was decided that PTs should also experience open inquiry while participating in IBSE101. By doing this, PTs would broaden their experience of IBSE.

4.2.1 Open Inquiry and Science Teacher Education

The use of open inquiry in science teacher education has been studied. Like when learning to teach by guided inquiry (Chapter 3), pre-service teachers face challenges when learning to teach by open inquiry. Anderson (2002) reports on some of the issues that teachers face when trying to use an inquiry-based curriculum. Included in these are teachers' limited understanding of the nature of science, limited content knowledge, and inexperience with inquiry approaches.

4.2.2 Criticisms of Open Inquiry

In a famous attack, Kirschner, Sweller, and Clark (2006) characterized "minimally guided instruction" as learning where "learners, rather than being presented with essential information, must discover or construct essential information for themselves", and "direct guidance instruction" as "providing information that fully explains the concepts and procedures that students are required to learn". They contended that the former moves the focus from knowledge towards experiencing the processes and procedures of the discipline exclusively. They also cited a number of studies that showed minimal guidance approaches to be inefficient and ineffective.

Hmelo-Silver, Duncan and Chinn (2007) correctly pointed out that Kirschner et al (2006) incorrectly grouped almost everything that is not direct guidance instruction together as minimally guided. However, even if we accept that Kirschner et al.'s paper (2006) was somewhat polemical, it provides some useful checkpoints for our DBR experiment. First we note that our definition of the inquiry spectrum does not include discovery learning, in which students explore phenomena without any teacher guidance at all. As Mayer (2004) showed, such approaches nearly always fail. Secondly, we do not advocate that PTs would use open inquiry exclusively. Like Olson and Loucks-Horsley (2000), we think that there should be a balance between developing discipline-based knowledge which guided inquiry is well suited to foster, and developing processes and procedures, which is more suited to open inquiry.

4.3 Video Analysis in Teacher Education

How PTs learn through video analysis has been investigated by several studies to date. Through video analysis, PTs can see real time examples of complex and subtle classroom interactions (Brophy, 2004). Many studies investigating the use of video analysis with PTs report that their learning can be influenced by the use of video analysis. For example, van Es and Sherin (2002) looked at what it meant for PTs to 'notice'. They found that by viewing and discussing video classes, PTs were able to interpret and analyse classroom activities in a more expert way. It has also been found that PTs can become more reflective over time if they have opportunities to observe teaching through video (Stürmer, Könings, & Seidel, 2013; van Es & Sherin, 2002; Blomberg, Stürmer, & Seidel, 2011).

Video analysis has also been used to study both pre and in-service teachers' Professional Vision. Seidel & Sturmer (2014) developed a video based instrument designed to test three specific aspects of PTs' Professional Vision: describing, explaining and predicting classroom situations. Sherin & van Es (2005) examined how video could be used to help PTs to 'notice' classroom events. The authors found that it is possible to change what pre-service teachers highlight through viewing and analysing teaching. Specifically they focussed on "what it means for expert teachers to be able to recognise significant features of the context in which they work" (p. 477).

Gamoran Sherin & van Es (2008) found that participating in a video club also influenced teachers' Professional Vision. They also reported that Professional Vision is a productive lens for investigating teachers' learning through video. Sun & van Es (2015) investigated how learning to analyse ambitious teaching practices could influence PTs' own classroom practice. PTs who participated in a video based course designed to develop their vision of ambitious practice engaged in more student centred practices while teaching. These included paying attention to student thinking during instruction, and creating opportunities to notice this thinking during instruction.

One potential issue in the use of video analysis is selecting appropriate videos to use. Arguments can be made for using either videos of PTs' own instruction or videos of other teachers exemplifying expert teaching. We have chosen for the vicarious experience of watching another teacher's IBSE instruction. This decision was informed in part by our own intuition, and in part by the knowledge that the PTs had already analysed videos of their own microteaching in the first year of their degree. Videos of the PTs teaching 'real' secondary school classes were not available, as they had not yet done a school based placement.

4.4 Developing a Conceptual Framework for Design Cycle 2

4.4.1 Cycle 2: Trialling Video Analysis and Content Knowledge Activities

4.4.1.1 Classical Probability Workshop

After Design Cycle 1, where PTs engaged in and critiqued IBSE activities, we had learned a number of things about PTs' Professional Vision, and how they engage in IBSE activities. Chapter 3 reports that PTs held a view of IBSE teaching that was quite limited. They held a very factual view of science teaching and tended to focus on just surface features of inquiry.

We identified PTs' familiarity with the scientific content of the materials they were given as one possible reason that they tended to focus on facts. In light of this, we decided to investigate the issue of content knowledge in more detail before embarking on a second iteration of the design experiment. This was done using a guided inquiry activity, based around a classical probability problem. The content required to complete the task consisted mostly of bringing together different elements of first year undergraduate physics and mathematics modules. The PTs were therefore not familiar the content unlike the content included in Cycle 1, and they would not have seen the different parts used at the same time. The activity was based on an activity developed by Crouse (2007) (Appendix C).

The activity is designed to guide students through a series of questions on the motion of a ball in a closed system. The ball undergoes uniform motion at two different levels in a stepped potential well, and spends a negligible time near the walls or transitioning between the two levels. A basic knowledge of classical mechanics is required for the students to relate the height of the well and the total energy of the ball to its speed and the time it spends at each of the two levels of the well. The latter is then used to first find and then define the probability density of finding the ball anywhere within the stepped well. Crouse (2007) designed the activity to help his students develop a sense for the meaning of probability density in quantum mechanics.

As with the activities in Cycle 1, PTs were asked to critique the activity at both a global level and a question by question level (see Section 3.6.1). Informal analysis of these critiques allowed us to gain some further insight into PTs' views on IBSE, and what aspects of their Professional Vision were evident after completing this activity. We found that there were different aspects of IBSE that PTs attended to when critiquing an activity that includes content that they are not familiar with. For example, PTs identified the development of their own thinking as a main goal of the activity. In some of the critiques, PTs talked about students' ability to think "critically". However, they still talked about this ability to think critically as a means to arrive at the correct answer, or to understand concepts correctly. There was no explicit mention of the value in being able to think critically per se. Another finding was that PTs identified links between questions as an important aspect of the activity, as they had done when critiquing Junior Certificate level experiments (see Chapter 3). After analysis of these critiques, it was decided it was worthy to retain the Classical Probability activity in Cycle 3 of the design experiment.

4.4.1.2 Video Analysis

One feature of Cycle 1 was that PTs did not view experienced professionals enacting IBSE; rather they were exclusively engaged in IBSE activities themselves, highlighting aspects of these activities, and then envisioning how these activities may look in their future classrooms. As previous research (outlined in Section 4.3) shows, engaging PTs in video analysis of IBSE activities can be a useful activity. Thus in Cycle 2 PTs analysed a video of an Irish teacher teaching a series of lessons on pressure. In the series of lessons shown in the video clips, students first viewed a short clip of a tanker being crushed. The students in the video then had to try to explain on a poster what had happened to cause the tanker to crush. The classes developed somewhat organically, with the teacher developing new activities for the next class based on needs that emerged. The workshop also required PTs to discuss and develop their own explanations of what had happened to the tanker.

One of the aims of the workshop was to ascertain what significant events in an inquiry classroom PTs could identify. To do this, the teaching video was edited into seven short clips, including those of a whole group discussion and students presenting their posters. While watching the clips, PTs were given guiding questions (Table 4.1) to discuss and write their thoughts on.

Table 4.1 Structure of the video workshop in Research Cycle 1B.

Clip No.	Purpose
1	**Discussion: Introducing students to pressure** What do students need to know before they begin? Where might students have problems? (misconceptions) What would the PTs like the students to know/understand by the end of the lesson(s) about pressure? How much information would the students need to be told? How would they teach the lesson(s)?
2	**PTs' own understanding of pressure** Show the video of the tanker being crushed, which the students' posters were based on. Get the PTs to make a poster under the same guidelines as the students of what they would like the students to have on their posters if it were their own class.
3	**Developing Students' Understanding** The PTs will be shown the posters made by the students in the class. They will be asked to develop a list of questions and can describe how they would develop students' understanding from what is on their posters to what they would like them to have on their posters.
4	**Videos** The PTs will be shown the group discussion video clip to show how the students worked together. This clip can be fast-forwarded just to give students an idea of how the students worked together and how the teacher helped to develop their understanding. The PTs will then be shown the presentations video clip to see how the students' understanding has developed throughout the class and again how the teacher interacts with the students based on their understanding. The PTs will discuss the videos in their groups, what they liked, what they disliked, what they would have done differently, how this compared to how they would have planned to teach the class, what they learnt.
5	**Conclusion Video** After watching the group discussion and presentation videos, the PTs, in their groups, will discuss how they would finish the class and bring together all the ideas and where they would like the students' learning to be at the end of the class. The PTs will then watch the video of the conclusion of the actual class and will discuss in their groups and as a class differences between how they would have finished the class and how the teacher finished the class. Again, they will discuss what aspects they liked, disliked, or would change.
6	**Closing Discussion (or Report):** • PTs will discuss their experience of watching the videos: o How did their initial ideas for the class compare to what they saw in the videos? o Did they learn anything new about inquiry? o Did they learn anything new generally (about pressure, other aspects of physics)

- How did their understanding of pressure compare to the students' understanding of pressure?
- Did their understanding change/develop throughout?
- Would they feel confident to teach a class in that style?

When the video analysis activity was complete, PTs were required to write a reflection on both the first and second parts of the workshop. PTs were given headings to guide them in their reflection. These headings asked them to consider what their thoughts on inquiry were before and after the workshop. The reflection sheet is given in Appendix D.

4.4.2 Description of the Conceptual Framework for Design Cycles 2 and 3

Before considering potential endpoints and research questions for Design Cycle 2, it was necessary to conceptualise the design cycle. Building on the literature discussed in Sections 4.2 and 4.3, we decided that PTs would experience open inquiry and also try and identify the important features of an open inquiry activity through the video analysis of an open inquiry activity being taught to a group of students. However, a number of things would also influence what PTs highlighted.

The conceptual framework for Design Cycle 2 proved satisfactory, and it was retained for Cycle 3. It was decided that there were three potentially interesting topics for investigation: (1) a deeper analysis of the changes to PTs' PV through the Classical Probability workshop, (2) a deeper analysis of the changes to PTs' PV through a video analysis workshop, (3) a new analysis of the discourse among PTs while they were trying to understand how the tanker could have imploded. We considered that doing all three would extend the Ph.D. too much, and felt that option (1) would be the least likely to yield new insights.

4.4.3 The Thought Experiment and Potential Endpoints for Cycle 3

After trialling both the Classical Probability and Video Analysis activities, it was decided that while both activities were worthy of inclusion in Cycle 3, an adapted version of the video activity was what would be studied in detail for this cycle. In what we term the Pressure workshop from now on, students would first carry out the same activity as the Junior Cert students; we would audiotape their conversations and analyse them. While taking place first in the Learning Cycle, in terms of research the analysis would lead us furthest from what we had learned from Cycles 1 and 2, and therefore we designated this Research Cycle 3B (which will be discussed in Chapter 5).

Instead of watching excerpts from a series of classes taught by the Irish teacher, we decided on a more focussed approach in which a continuous 32 minute US middle school class recording was analysed. This class is based on the same video of the imploding tanker. This change was made mainly for practical reasons. The video that was chosen was taken from from the Ambitious Science Teaching series of videos developed by an established research group at the University of Washington. This would enable PTs to watch further videos and teacher interviews from the same source. Moreover, as described in Section 4.5, a cohort of PTs from a US research university took part in Research Cycle 3A alongside a cohort of Irish PTs. A video from a US classroom with easy access for both cohorts of students was therefore a sensible choice.

4.4.4 Research Questions for Cycle 3

For this part of the design experiment we wanted to use video to allow the PTs to experience some complex and subtle classroom interactions. Up to this point, the PTs participating in IBSE101 experienced IBSE primarily through analysis and critique of guided inquiry activities. However, in using this approach, we found that while PTs paid attention to some of the purposes of IBSE, they still frequently related these to their own experiences from secondary school. A key question that we wanted to address was what the specific practices that PTs highlighted were while watching a video exemplifying IBSE teaching. Specifically there were three research questions:

> Q3A.1: What do PTs highlight when watching a video of an open inquiry activity?
>
> Q3A.2: Are there particular things that PTs highlight and code when they are asked to focus on student ideas?
>
> Q3A.3: What are the similarities or differences in the highlighting and coding practices of groups of PTs from different countries?

4.5 Setting

As part of this Ph.D. I spent 8 weeks a large public university in the Mid-Atlantic region of the United States. This allowed me to investigate how two separate groups of PTs participated in the Pressure workshop. The workshops were part of a broader science education module for both groups, IBSE101 at the Irish University, and PED400 at the US University.

4.5.1 Participants

Both groups of PTs comprised 18 students with an even gender balance. Some salient features of the groups are detailed in Table 4.2.

Table 4.2 Participants in the workshop for cycle 2.

Ireland	US
18 PTs (10 Female, 8 Male)	18 PTs (9 Female, 9 Male)
Year 2 of undergraduate science teaching degree	Secondary Science Majors
Will specialise in two of Physics, Mathematics,	8 Chemistry
Chemistry in Year 3	1 Physics
	2 Earth & Space Science
	7 Biology
Video analysis in groups of 2 or 3	Video analysis in groups of 2

4.5.2 The Workshop

The *Pressure* workshop was a three hour workshop that was split into two parts. While both parts of the workshop were linked, the results of each will be initially reported separately. This chapter reports on the second part of the workshop, which was the subject of Research Cycle 3A. The first part of the workshop is the subject of Research Cycle 3B and will be detailed in Chapter 5.

Briefly, in the first part of the workshop the PTs were shown a short video clip of an imploding tanker. They were asked to discuss the tanker before, during, and after the implosion in groups of 4 or 5, and draw their ideas on an A3 sheet of paper. In the second part of the workshop the PTs were asked to analyse a 32 minute video recording of a middle school class that was taught similarly in groups of 2 or 3. The video was taken from a website developed by the University of Washington (2014). The website is a collection of tools designed for use with teachers and teacher educators in the area of ambitious science teaching. Students in the video were expected to develop initial models about what caused the tanker to collapse. Specifically, the goals of the lesson that PTs viewed were:

- To get students' ideas on the table about the relationships between temperature, volume and pressure in gases
- To hear them talk about temperature, phases and pressures in everyday language
- To hear any preconceptions about pressure and forces.

We focussed on two particular aspects of PTs' professional vision as outlined in research questions 3.1 and 3.2. Data was collected via two similar but different mediums, due to local circumstances. PTs participating in IBSE101 were asked to fill out responses using Google Forms, while PTs participating in PED400 used Studiocode® to view and analyse the video. While watching the video, both sets of PTs were asked to respond to two questions, shown in .

Table 4.3.

Table 4.3 Questions asked to PTs during the *Pressure* workshop.

Question asked to PTs	Link to research question	Link to PV
Good teaching - Highlight and describe any times where the teacher is displaying good teaching. Include a description as to why you highlighted this clip	Q3A.1	Looking at the broader area of 'good teaching'.
Student Ideas - Highlight any times students have ideas that you think need to be considered. Include a description as to why you highlighted this clip	Q3A.2	Looking more specifically at how PTs deal with student ideas - a subset of good teaching

Responses to these questions formed the data to be analysed. For this part of the study, we wanted to be able to look at Professional Vision at two different levels. The first was in relation to the broad area of good teaching, while the second more specifically looked at how PTs paid attention to student ideas and what ideas PTs highlighted when prompted to do so.

There were several reasons for looking specifically at student ideas. The first was the nature of the lesson being used in the video. It was a lesson primarily designed to elicit students' initial ideas in the area of the gas laws. Secondly, we wanted to foster the idea of a student-focused approach to teaching from an early stage in the module. Levin, Hammer & Coffey (2009) report that attention to student thinking should be one of the priorities for teacher education. However they also note that this can be challenging for beginning teachers, noting that teachers' own educational background can be a reason for this.

> "One major reason that novice teachers struggle to attend to student ideas and reasoning is their participation in the social and institutional systems of public schooling, which encourage framings of teaching in terms of classroom management and curricular coverage." (p. 152).

Therefore we felt it was import to have PTs think about students' ideas at this early stage of their training.

4.6 Data

Both at the Irish and US university, 8 groups of PTs took part in the workshop. We have labelled the groups of Irish PTs with letters A-H, while the groups of US PTs were numbered 1-8.

Table 4.4 Number of highlighted episodes per group.

Good Teaching				Student Ideas			
IBSE101		PED400		IBSE101		PED400	
Group	**No. of Responses**	**Group**	**No. of Responses**	**Group**	**No. of Responses**	**Group**	**No. of Responses**
A	11	1	0[2]	A	6	1	12
B	16	2	21	B	9	2	19
C	18	3	13	C	3	3	6
D	6	4	7	D	4	4	8
E	10	5	11	E	10	5	10
F	20	6	14	F	14	6	9
G	17	7	11	G	9	7	7
H	10	8	6	H	4	8	4

The number of times each group highlighted a particular episode as good teaching or containing interesting student ideas is given in

[2] Responses looking at good teaching for this group were not recorded due to a technical error

Table 4.4. Quantitatively, we see that Irish PTs highlighted many more instances of good teaching, and some more instances of interesting student ideas. We will analyse the responses in more detail in Section 4.6.1.

4.6.1 Detailed Analysis of Highlighting by Group C

Table 4.5 and

Table 4.6 show a sample of the type of data collected. Each group marked times and a description as to why they highlighted each clip. Groups were not given any instruction on how many clips they should highlight, or what sort of detail they should provide in their descriptions. The video analysis data from Group C is shown in Tables 4.5 and 4.6 as a typical example of highlighting of “good teaching” and “student ideas”. Each line was analysed based on an emergent coding process (Miles & Huberman, 1994). Initial analysis focused on the areas of highlighting and coding. As elsewhere in the thesis, highlighting referred to what the PTs paid attention to under the specific headings, i.e. what they described was going on at the times that they marked. Coding referred to their reasoning (if any) about what was going on and how it related to their ideas about inquiry.

Table 4.5 Highlighting of good teaching by Group C (PTs from Ireland).

Group C	**Good Teaching**
Time	
42"	She's moving around classroom insuring they are ok with the work.
1'20"	Finding out the students own opinions and putting them on board displaying to rest of class. She's asking them to explain their answers in more detail, and getting them to think about what they are saying
5'53"	She's getting them to predict what they think is going to happen.
7'44"	Getting the students to think about why it crushes in on itself. Asking them questions to get them thinking. Asks a lot of students their opinions and not just one.
9'31"	Giving clear instructions. Getting them into groups to discuss their ideas together.
12'28"	Going around to the groups and asking them questions about their opinions and getting them to explain them to her.
17'28"	Using the students ideas to put forward her ideas . She sits at their level and isn't standing over them, interacting with them.
23'29"	She asks them to clarify their ideas, what happens inside the tank and gets them to explain that.
26'22"	Gives the students time to think about their ideas, explain them and she comes back to

	analyse their findings.
30'15"	She keeps questioning them, how and why, and getting the students to explain.
30'15"	She doesn't dismiss their ideas whether they are right or wrong.

Table 4.6 Highlighting of student ideas by Group C (PTs from Ireland).

	Student Ideas
Time	
3'30"	student asking about the size of the molecules.
5'45"	Students gave ideas what might of happened to the tanker.
10'05"	suggesting the speed of the molecules effects the outcome(G. 1)
11'35"	Hot air, cold air effect(temperature effect)(g.2)
14'12"	discussing the ideas of the pressure building up in the container. All groups are contributing to the exercise thoroughly..
17'20"	very extensive diagram (g.3) * each group has the idea of temperature changes between the outside and inside.
22'22"	group 4 using the idea of arrows going different ways to incorporate the pressure.
22'50"	students trying to teach each other, good class management by teacher. * students seem pretty engaged in the lesson.
29'35"	once the teacher gave them little hints, the group swayed towards a different idea about what is going on. * hard to hear students talking.

4.7 Answering the Research Questions for Cycle 3A

This section describes what aspects of "good teaching" and "student ideas" the PTs focussed on. Five aspects emerged from analysis of the highlighting and coding data. These are each described separately before linking these to answer the research questions for this cycle. Each is presented with supporting quotes. Section 4.8 then outlines how these areas of focus allowed us to answer the research questions.

Because the analysis process is somewhat different from that used in Research Cycle 1 (Chapter 3), we have used different terms. The five aspects PTs focussed on we have called "themes", and they lead to "claims". In hierarchical terms themes are comparable to the summary claims of Research Cycle 1, because they are based on all of the PTs' highlighting and coding. However, because we have already developed a language to describe how PTs highlight and code, we are not using metaphors. The claims used in

Research Cycle 3 are essentially the same as the “final claims” of Research Cycle 1, because they are generalisations based on the PTs’ work.

4.7.1 The main aspects of good teaching and student ideas PTs focus on

- **Theme 1: PTs focus on what students already know to help further their explanations.**

One of the first themes common across all groups was a focus on instances when the teacher tried to gather students’ prior knowledge about the subject. Some examples of this include:

> “Opened topic by asking class what the[y] knew about the topic” *[Group A, 00:01:00]*
>
> “Gave students a chance to give their own ideas to write down what they know about the topic” *[Group D, 00:00:59]*
>
> “Frames lesson - Collect students thoughts” *[Group 3, 00:00:59]*
>
> “Asking students for their ideas before the scenario. Summarizes students ideas” *[Group 6, 00:05:40]*

In all of these cases, the groups have paid attention to the teacher collecting the thoughts of the students at the start of the lesson. Many groups have highlighted the same time (00:00:59), indicating where they feel this is first happening. However, only Group 3 goes into detail about why the teacher might be doing this. They indicate that it is a way of framing the lesson.

- **Theme 2: PTs generally describe the actions of the teacher with little coding.**

PTs highlighted several instances focusing on what the teacher is physically doing e.g. “giving clear instructions” or “asking questions”. Most of the focus was on the actions of the teacher, with groups rarely going into detail about why the teacher may be doing this.

> “teacher goes around from group to group asking questions” *[Group E, 00:12:26]*
>
> “Going around to the groups asking them questions about their opinions and getting them to explain to her” *[Group C, 00:12:28]*
>
> “She walks around to each group seeing how they have progressed and guiding them towards their own answer” *[Group B, 00:12:00]*
>
> “Teacher summarizes the students’ ideas” *[Group 2, 00:05:59]*

In most of these cases, PTs simply re-write what they see the teacher doing on the video. However, in the third quote, group B go beyond just indicating what the teacher does. They give a reason as to why she might be doing this. This is discussed further in Section 4.7.2.

- **Theme 3: When PTs highlight student ideas, they often do not extend this to what may underpin these ideas.**

Along with being asked to highlight times of “good teaching”, PTs were also asked to highlight times where students in the video had ideas that they felt were important. For this, PTs paid attention to many common ideas. In many instances groups simply restated the idea, or described what students were talking about. For the most part, PTs did not go into further details about why these ideas are important, or what might underpin them.

> "Discussing the idea of the pressure building up in the container." *[Group B, 00:14:12]*
>
> "Students mention the molecules moving fast inside the tank" *[Group D, 00:10:38]*.
>
> "When student suggest the size of the molecule changes" *[Group A, 00:03:20]*
>
> "Student suggest water may have been sucked out of it." *[Group 2, 00:08:37]*

- **Theme 4: When PTs highlight student ideas, they sometimes reference the construction of knowledge and the quality of the students' statements.**

Many groups give at least one or two pieces of commentary on their highlighting of important student ideas that suggests an appreciation that knowledge is being constructed. The US PTs were more likely to state that this process involves using prior knowledge than the Irish PTs. The quality of particular statements is also commented on. In some cases these comments are problem-specific, in other cases they are general:

> "Talking about temperature trying to relate it to molecules"
>
> "Students are starting to piece their ideas together to understand the big picture"
>
> "Student gives opinion in full"
>
> "Student gives a better explanation of how molecules work"

- **Theme 5: When highlighting students' ideas, PTs also highlight the collaborative nature of the students' statements.**

There are many instances of PTs commenting on the collaborative nature or orientation towards other students' statements. For example,

> "Students trying to teach each other […] students seem pretty engaged in the lesson"
>
> "Students are sharing their knowledge of different states of gas/matter with the class"
>
> "Students trying to use everyday examples to explain why the tank imploded. Debating each others ideas"
>
> "Every student idea is very important as they are getting closer and closer to understanding the concept"

4.7.2 PTs' views of good teaching and noteworthy student ideas

A co-researcher and I used the 5 themes to generate two claims about PTs' Professional Vision. As before, these final claims are a generalisation based on the PTs' analysis of a specific teaching episode or artefact, but informed by their critiques of all five workshops.

Claim 1: PTs generally highlight relevant instances of both good teaching and student ideas when asked to do so.

PTs from both cohorts mostly highlighted many relevant instances of good teaching and student ideas, and did not highlight instances we would deem questionable. The first five minutes of the video shows the teacher asking a lot of probing questions, and PTs reference this. The teaching episodes and student ideas that they pay attention to are important and align with IBSE. However, highlighting of good teaching is rarely accompanied by any coding. Theme 3 shows that this is also frequently, but not quite as often, the case for highlighting student ideas.

Claim 2: PTs recognise that students' ideas derive from their own and other students' prior knowledge and experiences.

Through the use of video analysis we can see that PTs appreciate some of the affordances of open inquiry. Most groups highlight instances where students refer explicitly to making links to their prior knowledge, referencing the ideas of other group members, and coming to a better understanding of the problem on hand. This finding is somewhat surprising given the potentially restrictive nature of the headings given to the PTs.

4.8 More Insights into Professional Vision - Implications for DBR Study

The research described in the preceding sections allows us to answer the research questions posed in Section 4.4.4.

When asked to identify instances of good teaching and student ideas during an open inquiry activity, PTs from both Ireland and the US generally highlighted sensible episodes, but rarely give evidence of if and how they code these episodes. In terms of

PV these findings pertaining to an open inquiry activity are similar to those of Chapter 3 pertaining mosty to guided inquiry. Both of these facts suggest that the Pressure workshop is a suitable complement to the guided inquiry activities of Cycles 1 and 2.

When asked to highlight student ideas they felt were important, PTs' responses were often limited to doing just that. Encouragingly however, almost all groups gave one or more responses in which they evidenced an appreciation of the collaborative nature of constructing knowledge in open inquiry. Some groups also made judgements on the quality of some of the students' statements. This suggests to us that at least some of the PTs are beginning to think like an IBSE-oriented teacher.

Somewhat surprisingly, despite the potentially big difference in Apprenticeship of Observation between US and Irish PTs, we found many more similarities than differences in highlighting and coding. Quantitatively, Irish PTs highlighted more instances of good teaching and important student ideas. Qualitatively however, the US PTs were a little more likely to explain why they highlighted episodes, and mention the importance of prior knowledge more frequently.

Research Cycle 3A has shown that the Pressure workshop adds something valuable to IBSE101. As found in the literature (see e.g. Sherin & van Es, 2005), video analysis has been a valuable tool in helping PTs appreciate how students can construct knowledge, and how a particular teacher conducted herself in a constructivist classroom. Through the vicarious teaching experience their Apprenticeship of Observation was extended. From the PTs' video analysis it was possible to ascertain something about their Professional Vision that we were unable to elucidate before: an appreciation of the collaborative nature of the construction of knowledge in an open inquiry setting. Although the Irish PTs in particular are still at an early stage of their career, they are showing more evidence of thinking like an IBSE-oriented teacher than their predecessors who mostly experienced guided inquiry in IBSE101.

4.9 References

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Chapter 5 Characterising PTs' Discourse while Explaining Scientific Phenomena

5.1 Introduction

This chapter reports on Design Cycle 3 of the design experiment. As in Design Cycles 1 and 2, PTs engaged in and critiqued guided inquiry. However, in this iteration we looked at the characteristics of discourse that took place within a group of PTs during the first workshop of IBSE101. As with Design Cycle 2, the scientific phenomenon of interest was an imploding tanker.

Section 5.2 looks at the importance of classroom discourse for our PTs. In Section 5.3 we develop a conceptual framework for looking at classroom discourse. Many recent studies have looked at argumentation in the classroom, and the role it plays in the learning of science. Literature in the area of argumentation, sense making and transactive discussions in science education is reviewed, and we explain how these three ways of looking at classroom discourse contributed to the development of a conceptual framework for the third design cycle. It is argued that discourse in the science classroom is often complex, and episodes of discourse are characterised by a combination of argumentation, sense making and transactive discussions.

This conceptual framework informed a framework for analysis to investigate the patterns of discourse among a group of PTs. In line with the 'DBR Process', a thought experiment was formulated, which is discussed in Section 5.4. This thought experiment allowed us to develop research questions for Design Cycle 3. The sections following this explain how the PTs' discourse was characterised, and how this characterisation allowed us to answer the research questions. The final sections of the chapter discuss the implications for the overall design study, and examine how this design cycle furthers our understanding of PTs' Professional Vision.

5.2 From Design Cycle 2 to Cycle 3 - A need to look at discourse

In Design Cycles 1 and 2, the experiment looked at both PTs' written critiques and their highlighting and coding data from video analysis. Analysis of these first two iterations of the experiment showed that PTs held quite a narrow view of science teaching. They did show some signs of having acquired a narrow professional vision of teaching by inquiry in Design Cycle 2 but it was clear that not all of the goals of IBSE101 were achieved. Therefore, elements of the local instructional theory were modified. These are shown in Table 5.1 below. As discussed in Chapter 2, the local instruction theory (LIT) is presented from the PTs' point of view; therefore it is a representation of IBSE101 as PTs experience it.

Table 5.1 Outline of the local instruction theory.

LIT (PTs' experience)	Experience Inquiry	Reflect on Inquiry	New content through Inquiry	Vicarious Experience
Cycle 1	✓	✓		
Cycle 2	✓	✓	✓	✓
Cycle 3	✓	✓	✓	✓

During Design Cycle 2 PTs focused mainly on surface features of teaching when asked to highlight instances of good teaching in a video recording of an open-inquiry lesson. As part of the video workshop (Chapter 4) PTs had highlighted instances in the video where they felt students had ideas that were worth noting. Some, but not all groups highlighted instances in the video that showed they were paying attention to students' ideas and thinking about how they could be used. For example, reflecting on the video analysis during Design Cycle 2, one PT noted that

> *"While watching the video I learned that the teacher used a lot of different techniques to get the students to figure the answers out for themselves. I thought this approach to the class was very effective as the students seem to understand the answer more when they find it out for themselves."*

However, not all groups highlighted and coded class fragments in this way. Thus one of the goals of IBSE101, to place an importance on both doing and discussing the inquiry activities as a group, was not being met for all groups.[3] One of the important parts of the experiencing inquiry is PTs working together to answer questions and complete tasks. This is in line with one of the elements (discussing with peers) of IBSE defined by Linn, Davis, & Bell (2004).

In order to look at peer discussions in more detail, it was decided to investigate and characterise the discourse that PTs engage in while explaining scientific phenomena. To do this, as part of IBSE101 we introduced a *Pressure* workshop where PTs were given the opportunity to engage in an activity that mimics a group problem solving activity that might take place in the classroom. This would allow us to characterise the type of discourse that takes place among a group of PTs, therefore informing the overall design experiment. Being able to characterise this discourse would allow us to further investigate the PV of our PTs, and to make further decisions about the local instruction theory being developed. However, before these decisions could be made, a conceptual framework needed to be developed for the present Design Cycle. On top of this, a framework for analysis needed to be developed. As a starting point, three common ways of looking at discourse in learning science were looked at: argumentation, sense making, and transactive discourse.

[3] As noted in Chapter 4, during Learning Cycle 3 many groups did highlight at least one instance of learning collaboratively. However, this result was obviously not known before designing Cycle 3.

5.3 A Conceptual Framework for Cycle 3

5.3.1 Argumentation

In the last two decades, argumentation has become one of the most common ways of exploring the type of discourse that takes place in the science classroom. For example a number of policy and curriculum documents (e.g. Science Education Standards, 2012; OECD, 2012; Specification for Junior Cycle Science, 2015) mention the importance of evaluating scientific arguments in the classroom. Furthermore, helping students develop argumentation skills can be seen as one of the goals of scientific inquiry and science education. Duschl, Schweingruber, & Shouse (2011, p. 36) propose that students who are proficient in science are proficient in four key "strands", as they:

> (1) Know, use and interpret scientific explanations of the natural world;
> (2) Generate and evaluate scientific evidence and explanations;
> (3) Understand the nature and development of scientific knowledge
> (4) Participate productively in scientific practices and discourse

Within strand 2, Duschl et al. (2011) contend that generating and evaluating scientific evidence and explanations includes using evidence to construct and defend arguments. Berland & Reiser (2009) also claim that the construction of scientific explanations and taking part in argumentative discourse are practices that are essential components of scientific inquiry. Given all of this, it is understandable that so many studies have used argumentation as a framework for understanding scientific discourse.

Van Eemeren, Grootendorst, Johnson, Plantin, & Willard (2013) discuss different forms of argumentation from a theoretical viewpoint. According to Van Eemeren et al. (2013) argumentation generally has three different forms: analytical, dialectical and rhetorical. Jimenez-Aleixandre, Rodriguez, & Duschl (2000) summarise the differences and similarities in these types of arguments. The first of these, analytical arguments, usually proceed inductively or deductively from a premise or set of premises to a conclusion.

Examples of analytical arguments include deductions, syllogisms and fallacies. These types of argument are partly grounded in the theory of logic. Dialectical arguments are in the informal logic domain. These usually occur during discussion or debate. This type of argument involves reasoning with statements or premises that are not evidently true. Finally, in rhetorical arguments persuasion and knowledge take precedence ahead of the consideration of evidence.

Toulmin (1958) was one of the prominent influencers that contributed to our understanding of argumentation. In *The Uses of Argument*, Toulmin outlined his definition of an argument (Figure 5.1). This definition of an argument has been applied as a methodological tool used in the analysis of discourse in a number of different settings, especially in science education.

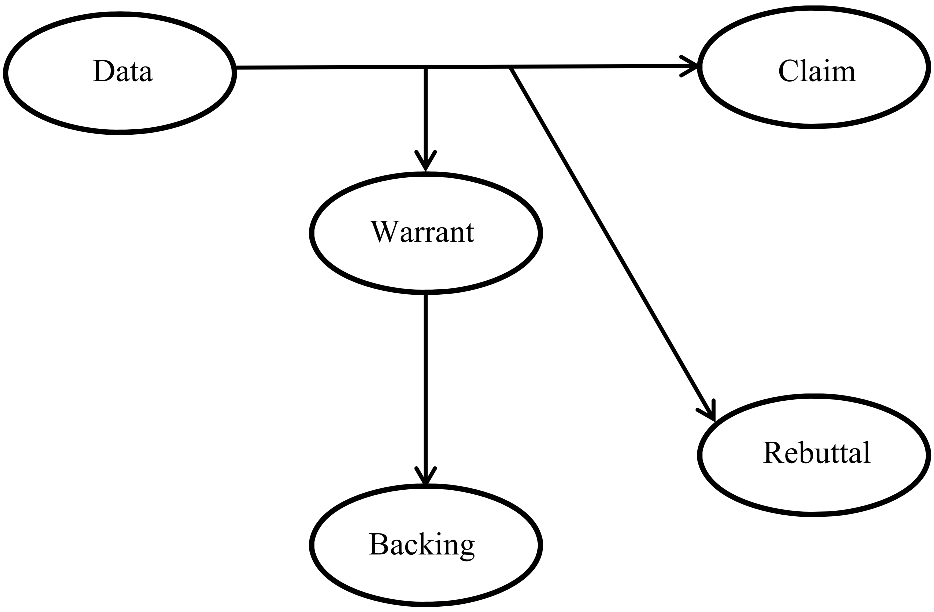

Figure 5.1 Toulmin's description of an argument (1958)

According to Toulmin, an argument consists of a number of different components. These are shown in Table 5.2 below.

Table 5.2 Toulmin's (1958) definition of components of an argument.

Element	Definition
Claim	"..an assertion put forward publicly for general acceptance"
Data ("Grounds")	"the specific facts relied on to support a given claim"
Warrant ("Qualifier")	"phrases that show what kind of degree of reliance is to be placed on the conclusions, given the arguments available to support them.
Backing	"generalisations making explicit the body of experience relied on to establish the trustworthiness of the ways of arguing applied in any particular case"
Rebuttal	"the extraordinary or exceptional circumstances that might undermine the force of the supporting arguments."

Other studies use different terms to describe these components based on Toulmin's original scheme. Some of these studies make a distinction between two types of operations, *epistemic* and *argumentative* (see e.g. Pontecorvo & Girardet, 1993). In making the distinction between these, they claim that argumentative operations are used by the speaker as a means of constructing and supporting their reasoning. These operations can be seen in Table 5.3 and Table 5.4 below.

Table 5.3 Description of Argumentative Operations (Pontecorvo & Girardet, 1993).

Argumentative Operations				
Claim	*Justification*	*Concession*	*Opposition*	*Counter-opposition*
Any clause that states a position (that can be claimed)	Any clause that furnishes adequate grounds or warrants for a claim	Any clause that addresses something to an addressee, admitting a point claimed in the dispute	Any claim that denies what has been claimed by another, with or without giving a reason	Any claim that opposes another's opposition, which can be more or less justified.

Table 5.4 Description of Epistemic Operations (Pontecorvo & Giardet, 1993).

Epistemic Operations				
Definition	*Categorisation*	*Predication*	*Evaluation*	*Appeal to*
A statement about the essential nature of an event or about the meaning of a word, including a shift of meaning	When something is considered as being a member of class, including a shift in categorization	The action of asserting something about a topic without any evaluative dimension	The act of asserting something about a topic with an evaluative dimension	The action of supporting a claim by appealing to something that the speaker considers relevant to the topic.

In another study, Jimenez-Aleixandre et al. (2000) explain the components of Toulmin's argument pattern. The particular problem that students were given in this study asked them to advise biologists studying what could be the cause of colour change in chickens. Jimenez-Aleixandre et al. used a more general description in their explanation of Toulmin's components of argumentation, outlined in Table 5.5.

Table 5.5 Description of an argument by Jimenez-Aleixandre et al. (2000).

Component	**Explanation**
Data	Hypothetical (in their case), and given in the problem statement
Claim (or conclusion)	The different hypothesis for the cases of the colour change
Warrants	Reasons which justify the connection between data and conclusion
Backing	A theoretical backing of general character
Qualifier	Specify the conditions for the claim
Rebuttal	Specify the conditions for discarding thee claim

As shown in Figure 5.1, according to Toulmin there are several components to an argument. The **claim** is a conclusion that is arrived at based on the data; the **data** is the evidence that is considered before making a claim. A **warrant** is the justification given in order to connect the evidence to the claim. These three components make up the main part of the argument. Stronger or more detailed arguments may also contain more components. **Backings** provide authority to the argument, and are usually used as extra evidence to justify the warrant. Finally, a **rebuttal** is a statement or counter-claim that refutes any component of the argument.

Along with being able to classify and describe argumentation in the classroom, researchers have also used these components of an argument to make judgments about the quality of argumentation that is taking place. This is generally known as Toulmin's Argumentation Pattern (TAP), or sometimes Toulmin's Argumentation Scheme. While several studies in both science and mathematics education have looked at patterns of argumentation among students, one of the most important studies in the development of methodological approaches to the analysis of argumentation and discourse was that of Erduran, Simon, & Osborne (2004). In this paper, the authors proposed several levels based on Toulmin's (1958) components of argumentation. These levels gave an indication of the quality of the argument that was taking place, based on the number of different components of TAP that were present in the episodes of discourse. In the study, they used the analytical framework Table 5.6 to assess the quality of argumentation.

Table 5.6 Erduran et al. (2004) levels of argumentation.

Level	*Description*
Level 1	Consists of arguments that are a simple claim versus a counter-claim or a claim versus a claim.
Level 2	Has arguments consisting of a claim versus a claim with either data, warrants, or backings but do not contain any rebuttals
Level 3	Has arguments with a series of claims or counter claims with either data, warrants, or backings with the occasional rebuttal.
Level 4	Shows arguments with a claim with a clearly identifiable rebuttal. Such an argument may have several claims and counter claims.
Level 5	Displays an extended argument with more than one rebuttal.

These levels allow researchers to not only describe the types of argumentation taking place, but also to quantify and assess the quality of the arguments. Some limitations of using TAP to assess the quality of argumentation are discussed in Sections 5.4 and 5.8.

In addition to Toulmin's framework, there are other frameworks used to analyse argumentation discourse. One of these is Walton's (1996) argumentation scheme. However, the large number (25) of types argumentation he identified in his analysis framework made it too fine-grained for our purposes.

It had been reported by Zohar (2008) that 'until recently, very little work has been done specifically about teacher education and professional development in the field of argumentation' (Zohar, 2008, p. 246). However, since then there have been some studies in the area of science teacher education. Ozdem, Ertepinar, Cakiroglu, & Erduran (2011) investigated argumentation schemes present while pre-service elementary teachers performed inquiry tasks. In this study, the authors investigated the types of argumentation schemes employed by a group of thirty five pre service teachers. These argumentation schemes were based on Walton's (1996) model of argumentation. The authors found that when pre-service teachers were making claims, or arguing for a case or an action, they often used premises other than reliable sources or observations to ground these claims. They suggested that designing inquiry environments that give opportunities for critical discussion can provide opportunities for discourse that supports argumentation. They also reported that pre-service teachers would 'cultivate the use of argumentation skills in their future science classrooms having gained them in their years of preparation in teacher education programs' (p. 2580).

5.3.2 Sense Making

While trying to explain what is going on in a scientific phenomenon, learners (students or PTs) go through a number of processes. Along with trying to argue about what is going on with claims and data, they must also try to make sense of the phenomena at hand, especially in more open forms of inquiry. Groups make sense of their reality through communication and social actions (McDonald & Kelly, 2012). Berland & Reiser (2009) identified three goals for constructing and defending scientific explanations. These are

> "(1) using evidence and general science concepts to make sense of the specific phenomena being studied; (2) articulating these understandings; and (3) persuading others of these explanations by using the ideas of science to explicitly connect the evidence to the knowledge claims." (Berland & Reiser, 2009, p. 29)

They also draw on the work of Dusch & Osbourne (2002), Driver, Newton, & Osborne (2000), and Jimenez-Aleixandre et al. (2000) to look at sense making in more detail. They outline the importance of sense making, and claim that the "nature of sense making must be influenced by the particular discipline with which the students are engaged" (p. 29).

For the *Pressure* workshop part of the Learning Cycle (and for all of IBSE101), one of the core elements of the local instruction theory was group work and collaboration. Sense making has also been looked at as both a social and individual endeavour. Ford (2012) outlines that for knowledge to become scientific knowledge, a claim must pass through a process of being certified by peers. This process of certification requires a rigorous critique. On top of this, the notion of opposition is important in the process of refinement of an explanation. He also makes the link between the individual and the community in the process of sense making:

> "Individuals basically play two roles—constructors and critics of knowledge claims—within scientific communities, and progress in the construction of knowledge results from social interactions according to these." (Ford, 2012, p. 211)

Building on this link between the individual and the group, the conceptual framework for this cycle also incorporates transactive discussions into PTs' dialogue.

5.3.3 Transactive Discussions

Transactive reasoning and cognitive change are linked theoretically from a Piagetian viewpoint. Piaget's proposal was that when children operate using each other's reasoning, the differences between their own reasoning and that of their partners becomes apparent. Resolution of these differences in reasoning (the cognitive conflict) provides a basis for a higher level of understanding. The importance of the group when making sense of a phenomenon is outlined by Driver et al. (2000). Their view of conceptual change is that it is

> "…dependent on the opportunity to socially construct, and reconstruct, one's own personal knowledge through a process of dialogic argument. Such occasions, rare as they are, do occur in science lessons when students are given the opportunity to tackle a problem in a group, or where, in a whole class situation, the teacher orchestrates a discussion to identify different lines of thought and invites students to evaluate these and move toward an agreed outcome." (Driver et al., 2000, p. 298)

During the Design Cycle 3 iteration of IBSE101, it was important to the process of making sense of a phenomenon that PTs worked as a group. King (1998) gives an example of children collaborating on a shared goal in the context of classroom learning as an example of a transactive cognitive partnership between peers. Here, she argues that learning is mediated by the peers themselves, and learners depend on each other for what and how they learn. The reason that this cognitive partnership is transactive in nature is that within it, scaffolding and guidance are mutual. On top of this, the appropriation of skills, meanings and knowledge is mutual appropriation. In peer-mediated learning, the learners depend on each other for what and how they learn. Teasley (1997) has defined the extent to which learners operate on the reasoning of their peers as transactivity. The discussions that PTs take part in during the workshop would be transactive in nature. However, in order to use the construct of transactivity as part of an analysis framework, it was necessary to develop codes that could be used to characterise lines of discourse.

Citing Berkowitz & Gibbs (1983), Kruger & Tomasello (1986) explain that a transactive discussion is one where an individual uses reasoning that operates on the reasoning of a partner or that significantly clarifies their own ideas. Kruger & Tomasello also outline that an individual transacts "when he or she extends, paraphrases, refines, completes, or critiques the partner's reasoning" (p. 681). In their study of transactive discussions with peers and adults, Kruger & Tomasello also looked at the orientation of transactive communication, that is if they were self or other oriented.

5.3.4 Argumentation, sense-making and transactivity - A conceptual framework

Different studies have used several terms to describe the cognitive processes that occur in collaborative and cooperative learning environments. These include "co-construction of knowledge", "collaborative knowledge instruction" and "reciprocal sense making" (Fischer, Bruhn, Gräsel, & Mandl, 2002, and references therein). The purpose of reviewing the areas of argumentation, sense-making and transactivity was to develop a conceptual framework which would guide the analysis of PTs' discourse. In relation to collaboratively explaining a scientific phenomenon, these three concepts are inherently linked. Therefore, the combination of argumentation, sense-making and transactivity would provide the map to explore the dialogue of PTs. On top of this, we wanted to explore the orientation of PTs' questions, responses and statements. This would inform us of the type of interactions that were taking place in the group. This conceptual framework is shown in Figure 5.2. Its implementation is detailed in Sections 5.6 - 5.8.

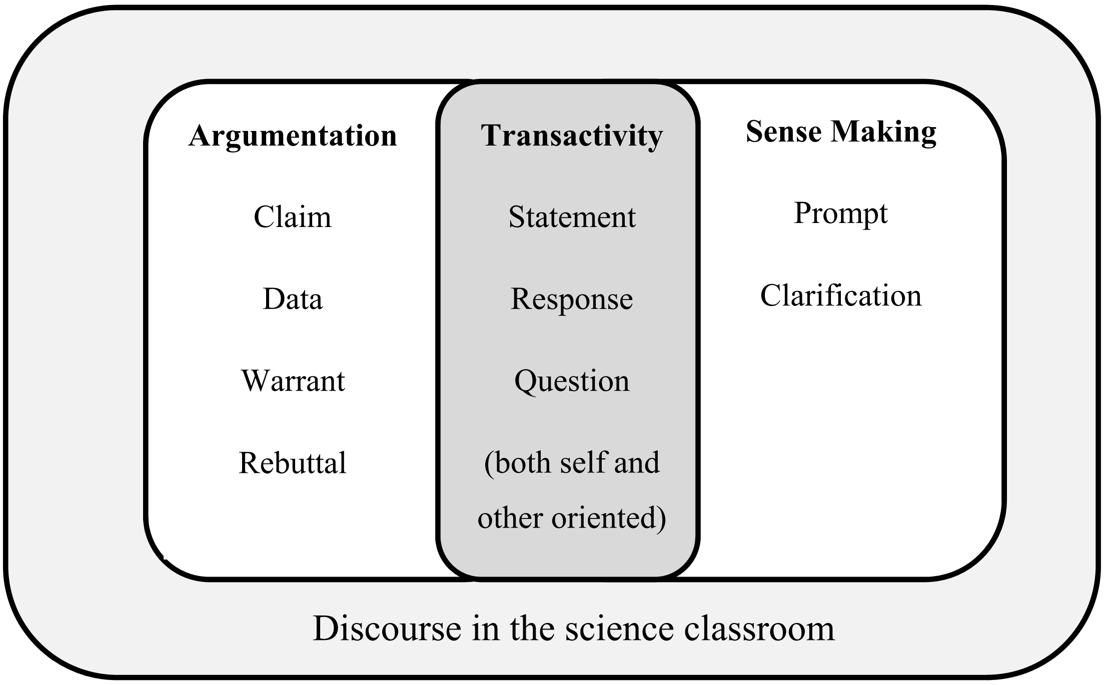

Figure 5.2 Conceptual framework combining argumentation, sense-making and transactivity.

5.4 Thought Experiment for Design Cycle 3

5.4.1 Thought experiment and potential endpoints

At the start of the *Pressure* workshop, PTs were asked to explain a phenomenon – the implosion of a steam-cleaned tanker – in as much detail as they could. Drawing on the conceptual framework, it was hypothesised that the type of dialogue that takes place in the science classroom is transactive in nature, and combines both argumentative dialogue and sense-making dialogue. In keeping with one of the broader aims of IBSE101, that is engaging PTs in the practices that take place in the IBSE classroom, we wanted to engage PTs in a group discussion where they needed to explain a scientific phenomenon. In doing this, we would be able to look at potential characteristics of PTs' dialogue, which would help inform future design cycles. It was also envisaged that the orientation of transacts is important, as students often reason individually, but aloud when working as part of a group.

5.4.2 Research questions for design cycle three

Taking the conceptual framework into consideration, and considering the potential endpoints, the following research questions were developed:

> 3B.1. Using a conceptual framework combining argumentation, sense making and transactive turns, is it possible to characterise the discourse of PTs?
>
> 3B.2. If so, are there differences and similarities in episodes of discourse?
>
> 3B.3. How does this analysis inform future design cycles, especially with regard to PTs' Professional Vision?

The first research question is related to the exploratory nature of this Research Cycle. The thought experiment for the design cycle envisaged that before being able to relate how PTs' discourse related to their Professional Vision, it would be necessary to explore the characteristics of this discourse. The second question explores this idea in more detail. In order to inform future design cycles, it would also be necessary to compare different episodes of discourse. If there were similarities or differences in the characteristics of discourse in different episodes, this could then be studied in more detail in order to look for reasons for this. The third research question is related more generally to the overall design experiments: could this sort of analysis enable us to make decisions about future cycles of IBSE101? As one of the goals of the module is to broaden PTs' Professional Vision, answering this question would also aid in the development of future design cycles.

5.5 The Workshop

During Cycle 3, 25 PTs took part in the *Pressure* workshop, which took place during the first week of IBSE101. They worked in groups of either 4 or 5. At the start of the workshop, PTs were shown a short video clip of an imploding tanker.[4] A screengrab from the video is shown in Figure 5.3.

Figure 5.3 Screengrab of tanker video.

[4] The clip and introduction used were the same as that in the teaching video in cycle 2. The video can be found at https://www.youtube.com/watch?v=Zz95_VvTxZM

The phenomenon was introduced as follows:

> *"A rail tanker had been steam cleaned. After the process, the valves of the tanker were closed and the tanker was left overnight. When the workers returned the next morning, this is what they found."*

The PTs were instructed to discuss (as a group) the tanker before, during, and after the implosion, and draw their ideas on an A3 sheet of paper. This part of the workshop lasted for about one hour, which included groups presenting a summary of their explanations at the end. During the workshop, groups mostly worked on their own in developing their explanations. At times during the workshop a co-researcher or I would ask the group some questions to help further their explanations. We had agreed beforehand what kind of questions to ask and answers to give. The types of questions asked were general probing questions about what the group had been doing, along with some questions about what they had drawn. We wished to interfere with their construction of knowledge as little as possible.

As far as the learning trajectory goes, the main aim of the workshop was to give PTs an experience of open inquiry. At the end of the workshop, PTs were also asked to write a one page semi-structured reflection on the workshop. They were given four headings to help them reflect, but were allowed to relate these to any part of the workshop. The guiding headings were 1) Something you have learned, 2) Something that stood out, 3) How your model of what happened developed as you drew your poster and 4) Something you are still unsure of. The main source of data for the Research Cycle was the transcript of the dialogue. However, the reflections were useful as a source of triangulation data to explore possible implications for the overall experiment in light of Design Cycle 3.

5.6 Characterising Discourse

5.6.1 Data Collection

Six groups of PTs (with either 4 or 5 PTs per group) took part in the *Pressure* workshop. Their conversations were recorded from the instant they began their explanations, after watching the clip of the tanker implosion. Each group discussed the problem for about 53 minutes. As one of the goals of this design cycle was to investigate if it was possible to characterise the type of discourse that takes place, it was decided to just analyse one of the group's discussions. The group was chosen at random from the set of six groups. The 53 minute discussion was transcribed and anonymised before analysis. During transcription, the discussion was broken down into 243 individual lines of discourse (from four students and two instructors). These 243 lines of discourse provided the data for analysis, which is given in its entirety in Appendix E.

5.6.2 Identifying Episodes of Discourse

The next stage of the analysis involved breaking the transcript into individual episodes for analysis. To do this, the full transcript was read, and different parts of the conversation were coded according to theme. Lines 1-13 of the conversation are shown below as an example.

Lines 1-13: [00:01:11 - 00:02:23]

1. Jim: Let's actually find out what happened then
2. Barbara: The pressure in the tank
3. Jim: Is less than the pressure outside
[pause]
4. Jim: That only happened because the valves were left open
5. Denise: Closed
6. Barbara: Closed
[pause]
7. Barbara: So the valves were left closed
8. Jim: So if they had been open there would have been…

9. Denise: …there would have been air
10. [pause]
11. Jim: Do we… define what pressure was?
12. Barbara: Huh?
13. Jim: Do we have to define what pressure is? If we are teaching this?

There are three pauses in the above excerpt, but not every pause delineates an episode. The group are starting out with the problem and discuss an initial idea about pressure. In lines 1-9 they are talking about the mechanics of the problem, and trying to decide if the valves of the tank were left open or closed. In lines 11-13, the conversation took a different turn: the group started talking in more detail about pressure, and its definition. Therefore lines 1-9 were coded as episode 1 for analysis, and lines 11-16 formed the start of episode 2. The discourse was similarly broken into thirteen episodes in total, covering 243 lines of discourse. The themes of each episode are summarised in Table 5.7.

Table 5.7 Summary of themes for each episode.

Episode	*Theme*
Episode 1: Lines 1-9	PTs begin to make sense of the problem, talking about the setting.
Episode 2: Lines 11-18	PTs are taking in more detail about pressure.
Episode 3: Lines 19-34	PTs return to talking about the valves on the tanker.
Episode 4: Lines 36-44	PTs try to link the present problem to something they have seen before.
Episode 5: Lines 45-68	An exchange between the instructor and PTs.
Episode 6: Lines 70-94	PTs talk about molecules for the first time.
Episode 7: Lines 98-106	After a long pause (~1 min) PTs start to link molecular motion and pressure.
Episode 8: Lines 107-137	An exchange between the instructor and PTs
Episode 9: Lines 140-168	PTs talk about the relationship between pressure and volume.
Episode 10: Lines 169-194	PTs talk about the gas laws.
Episode 11: Lines 195 - 208	PTs attempt to relate the gas laws to the specific phenomenon.
Episode 12: Lines 209 - 227	An exchange between the instructor and PTs
Episode 13: Lines 228 - 243	PTs consider the tanker in terms of molecular motion, pressure, temperature, and energy

Table 5.7 gives the final set of episodes. After an initial determination, the entire discourse was re-read, and any necessary revisions were made. The most contentious boundaries were those that lacked a natural pause in the conversation. An example of this arose in the transition from episode 10 to episode 11, contained in lines 192-197:

192: Cheryl: Because the volume does change when those two things are changed
193: Barbara: Yeah
194: Denise: Yeah
195: Barbara: They're proportional, so as temperature increases the pressure increases. And volume…
196: Denise: And somehow the pressure is going to have to go down…
197: Jim: And volume decreases though

On first reading it was thought that lines 192-197 were part of the same episode. However, on re-reading the discourse a co-researcher and I determined that the discussion takes a different turn in line 195, despite the absence of a noticeable pause, and moves back to the task that PTs are trying to solve. Although episode 10 did not end with a pause or break in conversation, we coded line 195 as marking the start of episode 11. When the conversation was broken up into individual episodes, the next stage of the analysis was to characterise each episode, drawing on the conceptual framework discussed in earlier sections of this chapter.

Table 5.7 allows us to see how the PTs' dialogue progressed in the space of 50 minutes. Thus, whatever the shortcomings in argumentation we identify in individual episodes, it is clear that from a sense making point of view the students make real progress with little input from the teacher.

5.6.3 Detailed Analysis of Individual Episodes

In addressing the first research question, and drawing on the conceptual framework, we wanted to see if it was possible to characterise each episode of discourse using a combination of argumentation, sense making and transactive turns. All of these elements were carefully chosen: argumentation because it is an important part of what we want students to be able to achieve; sense making because the open-ended nature of explaining the tanker implosion necessitates it; transactivity because the groups of PTs are expected to co-construct reasoning in a way that significantly depends on each other's contributions.

In order to do this, each line in each episode was coded. These codes were informed using the conceptual framework. This is represented in matrix form in Table 5.8.

Table 5.8 A blank discourse matrix.

	Statement		Question		Response	
	Self - Oriented	Other - Oriented	Self- Oriented	Other - Oriented	Self - Oriented	Other- Oriented
Claim						
Data						
Warrant						
Rebuttal						
Prompt						
Clarification						

The first four rows of the table represent the components of argumentation, while the bottom two rows refer to utterances that are not part of an argument but are primarily a means of keeping the conversation going. The different columns represent the type of discourse, and whether its orientation was self or other oriented. This is an extension of the ideas of Kruger & Tomasello (1986), discussed in the conceptual framework.

During the process of coding, the transcript was read by two researchers. For the purpose of analysis, definitions of each of the codes were first decided. The definitions for each of the codes drew heavily on the conceptual framework for the design cycle. Table 5.9 shows the final definitions for each of the codes. For the elements of argumentation, the codes were defined based on the codes used by Erduran et al. (2004). Transactive codes were defined based on the work of Kruger & Tomasello (1986).

Table 5.9 Final definitions for each code used in the analysis framework.

Code	Definition
Claim	The conclusion whose merits are to be established.
Data	Information provided within the learning environment that can be used to support or contradict a claim
Warrant	The reason that is used to justify the connections between the data and the conclusion
Rebuttal	(Counter)-claim stating that an earlier claim is not true
Prompt	Any conversational turn that aids the flow of discourse
Clarification	A conversational turn or request that helps to reduce ambiguity
Statement (S)	Spontaneously produced critiques, refinements, extensions or significant paraphrases of ideas
Question (Q)	Spontaneously produced requests for clarification, justification or elaboration of the partner's ideas
Response (R)	Clarifications, justifications or elaborations of ideas in answer to a transactive question
Self - Oriented (SO)	PT speaking but not directed at another PT
Other - Oriented (OO)	Spoken in response to another group member/instructor

The first step in the process of analysis was to populate this matrix for each episode. The codes that were applied to episode one is shown in

Table 5.10. Each of the 13 episodes of discourse was coded using the same method.

Table 5.10 Codes applied to episode 1 of discourse.

Line No.	Speaker and text	Code
1	Jim: Let's actually find out what happened then	Prompt - OOS
2	Barbara: The pressure in the tank	Claim - OOS
3	Jim: Is less than the pressure outside [pause]	Claim - OOS
4	Jim: That only happened because the valves were left open	Claim +Warrant - SOS
5	Cheryl: Closed	Rebuttal - OOR
6	Barbara: Closed [pause]	Rebuttal - OOR
7	Barbara: So the valves were closed	Data - OOS

8	Jim: So if they had been open there would have been…	Claim - OOS
9	Denise:…there would have been air	Claim - OOS

To illustrate the coding process we describe how the first episode was coded. In line 1, Jim makes a statement that has nothing to do with forming an argument, but is aimed at getting the group started. Coding this utterance as a prompt in the form of an other-oriented statement is quite unambiguous in our framework. In line 2, Barbara utters a half-sentence. We have categorised this statement as an other-oriented claim (as opposed to a prompt) because it introduces for the first time the notion that pressure is relevant to explaining the phenomenon. From the transcript alone it is hard to judge whether she is essentially talking to herself or offering this to the group as a means to get the conversation going – on listening to the audiotape, we felt it was more likely to be the latter. In line 3 Jim introduces the claim that the pressure inside the tank must be compared to the pressure outside implicitly, and states that in fact the pressure inside must be less. We have decided to categorise this as a other-oriented statement, because it appears to finish Barbara's statement rather than his earlier prompt.

In line 4, after a pause, Jim resumes his own reasoning with both a claim and a warrant. Primarily because he appears to build on his on previous statement, we have categorised the utterance as self-oriented. In lines 5 and 6, Cheryl and Barbara both correct Jim, and rebut that the valves were in fact closed.

In line 7, Barbara states that the valves were closed. In contrast to line 4, we have categorised this statement as data, rather than a claim, repeat rebuttal, or prompt. The definition of "data" in Table 5.9 fits this utterance perfectly, since the information was both as a consequence of lines 4-6 and as a start to line 7-9. In line 8 Jim appears to start a new line of reasoning: imagining what would happen if the valve had been left open. The statement seems to have been triggered by the data offered by Barbara. We therefore categorised it as an other-oriented statement. While we could have categorised it as a response, we reserve that label for reactions to more explicit questions. In line 9, Denise finishes his sentence for him, and appears to make an implicit claim about the air having left the tanker to create a vacuum.

In this way, we coded the entire discourse of Group 1. We acknowledge that alternative interpretations are possible, which is a common finding when applying argumentation frameworks (see e.g. Kelly, Druker, and Chen, 1998; Erduran, 2008). For example, in Table 5.10 line 4 is rated as including a warrant; it could be argued that this excerpt should be rated as including data. The utterance “the valves were left open” could be seen as merely “information provided within the learning environment that can be used to support or contradict a claim”; we interpreted it as a “reason that is used to justify the connections between the data and the conclusion”. We have found it impossible to define mutually exclusive categories, but have been able to ascertain that our main conclusions would be unaltered by reasonable alternative assignments.

5.7 Results

5.7.1 Discourse matrices for each cycle

In this section, matrices for each episode of discourse are presented. The dots represent each instance a line was classified with a particular code. The reason that this form of data representation is used is that at a glance it is quite easy to see the distributions of codes (or dots) for each episode. The shaded area (bottom two rows) represent the non-argumentation elements present in the episodes. The non-shaded areas represent elements of argumentation. Looking across the matrix horizontally we can see the orientation of each line – that is, if they are self or other oriented, along with the transactive nature of the line.

Lines 1-9 - Episode 1

Table 5.11 Discourse matrix for Episode 1.

	Statement		Question		Response	
	Self	Other	Self	Other	Self	Other
Claim	•	••••				
Data		•				
Warrant	•					
Rebuttal						••
Prompt		•				
Clarification						

In the first episode, PTs are at the initial stages of coming to an understanding of the problem they are given. It is characterised by a large number of claims, which are self-oriented. In total there are 5 claims in this episode, 4 of which are other oriented. These characteristics are expected at this stage of explaining a phenomenon. PTs are developing an explanation, so at this early stage many of the lines of discourse are simply statements about what they know already, or about some information they may have been given.

Another characteristic that we can see from the matrix is the high number of statements. 80% of the lines in this episode were coded as statements. Some possible reasons for this are discussed in Section 5.8.

Lines 11-18 - Episode 2

Table 5.12 Discourse Matrix for Episode 2.

	Statement		Question		Response	
	Self	Other	Self	Other	Self	Other
Claim						
Data						•
Warrant						
Rebuttal						•

Prompt	•	••	•
Clarification			•

During this episode, PTs had moved to the next stage of their explanation, where they begin to hypothesise that the reason the tanker exploded had something to do with pressure. Within this episode there are no claims, as they are merely trying to define pressure. Comparing this to the first episode, we see very different characteristics. All of the lines of discourse in the episode are either questions or responses. There is also a shift to the non-argumentation end of the matrix.

Lines 18-34 - Episode 3

Table 5.13 Discourse matrix for Episode 3.

	Statement		Question		Response	
	Self	Other	Self	Other	Self	Other
Claim	•		•		•	
Data	••		•			
Warrant						•
Rebuttal						••
Prompt	•					••
Clarification			•			

This episode is the first to include all three transactive elements (statements, questions and responses). The general pattern of the episode is a statement, followed by response. 62% of the lines are in the argumentation section of the matrix. The PTs mainly formed a narrative about what happened (the tanker was steam cleaned, were the valves open or closed), and likened it to a crushed can experiment they had seen before.

Lines 36-44 - Episode 4

Table 5.14 Discourse matrix for Episode 4.

	Statement		Question		Response	
	Self	Other	Self	Other	Self	Other
Claim	•••	•		•		•
Data	•	•				
Warrant	••					
Rebuttal						•
Prompt						
Clarification		•				

In this episode, PTs have moved beyond understanding what the problem is asking them to do, and are in a sense making a fresh start to trying to explain the phenomenon. In trying to begin their explanation, they are for the most part listing relevant physical quantities, but in the last two statements they make connections to previous experiments and personal experiences. Similar to the earlier episodes, the interactions are a roughly even mix of self and other-oriented. Most of the lines in this episode, however, are coded as statements.

Lines 45-69 – Episode 5

Episode 5 is not included in this analysis or represented in matrix form, since it comprised a lengthy interaction with one of the instructors. It is therefore very different in nature. In this episode, the instructor confirmed that the tanker valve was closed after steam cleaning, and that the tanker was cooling overnight. He also ensured that the conversation started to include the notion of molecules.

Lines 70-94 - Episode 6

Table 5.15 Discourse matrix for Episode 6.

	Statement		Question		Response	
	Self	Other	Self	Other	Self	Other
Claim	•	•••••		•		•
Data		•••••				
Warrant	•	•				
Rebuttal						•
Prompt		••		••		••••
Clarification				•		

In this episode we can see that the ratio of argumentation to non-argumentation statements is roughly 2:1. Statements dominate questions and responses in approximately a 2:1:1 ratio. During this episode PTs are constructing a pictorial representation of the air inside the tanker, and they reiterate the narrative from a microscopic level (i.e. what happens to the molecules).

Lines 98-106 - Episode 7

Table 5.16 Discourse matrix for Episode 7.

	Statement		Question		Response	
	Self	Other	Self	Other	Self	Other
Claim	•	••		••		•
Data						
Warrant		••				
Rebuttal						
Prompt		•		•		
Clarification						

In this episode statements and claims are again dominant. The PTs here mostly recapped what physical quantities (pressure, temperature, volume) were relevant to understanding the phenomenon they were trying to explain.

Lines 107-139 – Episode 8

This is the second extended period of interaction with an instructor. Most of this episode is taken up by discussing the pictorial representation the PTs had made of the tanker, including prompts to draw molecules on the outside of the tanker and to represent molecular motion pictorially. The PTs were prompted to think about the effect of temperature change on molecular speeds.

Lines 140-168 - Episode 9

Table 5.17 Discourse matrix for Episode 9.

	Statement		Question		Response	
	Self	Other	Self	Other	Self	Other
Claim	•	••••••		•••		•
Data	•	•				
Warrant		•••			•	
Rebuttal			•	••		
Prompt	•	•••••		•		••
Clarification		•		••		

In this episode the PTs are working hard to come to an understanding of how the air behaves inside the tanker. They have incorrectly generalised the notion of expansion on heating, which is generally valid for solids and liquids, to gases, including the notion of "expanding molecules". When trying to link these notions to the concept of pressure on the tanker, they realise that something is amiss. The relatively high proportion of non-argumentative utterances arises mostly from encouraging whichever PT is trying to combine elements of reasoning. At the end of this episode, they decide to "look it up", whithout clearly defining what they will look up.

Lines 169-194 - Episode 10

Table 5.18 Discourse matrix for Episode 10.

	Statement		Question		Response	
	Self	Other	Self	Other	Self	Other
Claim	••	••			•	••••••
Data		•••				••
Warrant	•••					
Rebuttal		•				
Prompt				••		•••
Clarification						•••

In this episode, the PTs have found up a number of gas laws (due to Boyle, Charles, Gay-Lussac) in equation form. They are then trying to link these equations to the qualitative discussions they had had about pressure, temperature, and volume, but soon revert to focussing on the equations only.

Lines 195 - 208 - Episode 11

Table 5.19 Discourse matrix for Episode 11.

	Statement		Question		Response	
	Self	Other	Self	Other	Self	Other
Claim	•	••			•	•••
Data		•				
Warrant	•					•
Rebuttal				•		
Prompt		•				•
Clarification			•	•••		

During this episode, the PTs returned to discussing the equations that represent the various gas laws and their earlier qualitative discussions. This time however they are succedding in doing so. Much of the discourse is about proportionality, and which of the three quantities are proportional to each other. The large number of lines that are coded as other oriented indicate that the group are using each other's ideas to construct their explanation.

Lines 209-227 – Episode 12

This is the final episode in which a prolonged interaction with an instructor takes place. In summarising their thinking, the PTs come back to the idea of the gas contracting when cooling down, and introduce for the first time the notion of energy (in the incorrect context of it being created in collisions). The instructor brings the conversation back to pressure, which the PTs link to foce and strnegth inside the air inside the tanker. The PTs agree that the molecules somehow cause pressure.

Lines 228 - 243 Episode 13

Table 5.20 Discourse matrix for Episode 13.

	Statement		Question		Response	
	Self	Other	Self	Other	Self	Other
Claim		•••			•	•
Data		•				•
Warrant		•				
Rebuttal						•
Prompt				••		•
Clarification				•••		

In the final episode, PTs have arrived at a satisfactory explanation (for them) about the phenomenon. Details of this episode are discussed in detail in Section 5.9.

5.7.2 Distribution of codes for each episode

The tables below show the distribution of codes for each of the episodes. For these tables, the distribution of codes in episodes where PTs were interacting with an instructor is not included.

The first table (Table 5.21) shows how the lines of discourse in each episode varied between argumentation and sense-making dialogue. The data in this table shows us the characteristics of different episodes, and is useful for comparing different episodes, which is discussed in the following sections.

Table 5.21 Distribution of codes for each episode.

	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	E13
Argumentation (%)	90	50	60	92	•	64	80	•	63	71	65	•	60
Non-Argumentation (%)	10	50	40	8	•	36	20	•	37	29	35	•	40

Table 5.22 shows the nature of transactivity for each episode. It shows the distribution of codes for each episode, detailing if they are statements, questions or responses.

Table 5.22 Nature of transactivity for each episode.

	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	E13
Statement (%)	80		40	75	•	60	60	•	59	38	35	•	33
Question (%)	0	50	10	8	•	16	30	•	28	7	30	•	33
Response (%)	20	50	50	17	•	24	10	•	13	55	35	•	33

Finally, Table 5.23 shows the distribution of codes looking at if they are self and other oriented.

Table 5.23 Distribution of codes as self oriented or other oriented.

	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	E13
Self - Oriented (%)	30	40	50	50	•	8	10	•	16	21	24	•	7
Other - Oriented (%)	70	60	50	50	•	92	90	•	84	79	76	•	93

5.8 Analysis of discourse - Affordances of the framework

Looking at the overall characteristics of the dialogue, we can see PTs talk about the physics of the scientific phenomenon they are trying to explain on two different levels: macroscopically and microscopically. PTs begin discussing the problem by talking about things at the macroscopic level, at which they can see. They start by talking about pressure, a relevant physical quantity, and whether the valves on the tanker are open or closed. In this way they are beginning to making sense of what they are being asked. They are not yet piecing together what they need to know in order to help explain what is going on.

1. Jim: Let's actually find out what happened then
2. Barbara: The pressure in the tank
3. Jim: Is less than the pressure outside
[pause]
4. Jim: That only happened because the valves were left open
5. Denise: Closed
6. Barbara: Closed

Immediately they have indicated that they know that pressure, or a difference in pressure, is one of the reasons why the tanker imploded.

In a TAP framework, episode 1 discussed above would probably be rated as "level 1" argumentation, which suggests that it is not a very valuable utterance if seen as part of an argument. However, from the point of view of understanding the problem, the episode is crucial: the PTs were establishing what has happened. There is more to Jim's claim in line 4 than just having misheard or misunderstood that the valves were left open instead of closed: many PTs implicitly or explicitly assumed that the air inside the tanker had to be in direct contact with the air outside for the implosion to happen. The claims and rebuttals made were therefore not part of a logical high-level argumentation pattern, but were primarily about how to start explaining the phenomenon.

In episode 2 the PTs built on this idea, and discussed further what their understanding of pressure is.

11. Jim: Do we… define what pressure was?
12. Barbara: Huh?
13. Jim: Do we have to define what pressure is? If we are teaching this?

14. Barbara: Yes. Pressure is force divided by area.
15. Cheryl: I think we have to find out why that is, why it has happened.
16. Jim: But we have that in one line - pressure
[Pause]
17. Jim: So what's pressure?
18. Jim: What is the standard atmospheric pressure?
20. [Pause]

The PTs were still trying to understand the 'problem' - that is they had not started to talk about the phenomenon itself, nor had they started to explain what had happened. Instead they were wondering what they already knew that will help them. Looking at Table 5.12, we can see that the transactivity of this episode is different to the first. It has an almost even mix of questions and responses, and these are both self and other oriented.

During episode 7, about 15 minutes after the PTs had started talking about the problem, the conversation had progressed considerably:

98: Denise: So surely it moved closer because if you are using a steam cleaner you are adding more molecules to it.
99: Barbara: Well in the general picture we know that the…we know there is more pressure because we are adding heat.
100: Jim: The change in temperature is causing it to get smaller isn't it?
101: [Pause]
102: Jim: So when they add the volume…when they put in the vacuum it loses all of its atmospheric pressure, yeah?
103: Barbara: Yeah the pressure increased.
104: Jim: The pressure increased?
105: Barbara: I'm not certain.
106: Jim: It is actually, yeah.

If we were to analyse lines 98-100 in terms of a TAP framework, we would say that the three students each start their own chain of reasoning: in lines 98 and 99 there is a claim and a warrant, in line 100 there is a single claim. None of the lines are related in a logical chain, though it could perhaps be argued that line 99 is in a sense a counterclaim to line 98.

In our framework, the episode is characterised differently. We see lines 98-100 as three separate but related offerings made by three different group members in an attempt to start to make sense of the situation and list relevant physical quantities. The transactive discourse element of our framework allows us to characterise each line as other-oriented thus allowing us to make a link between the three lines. Lines 98 and 99 are coded as statements, line 100 as a question.

After a short pause the discourse resumes. In TAP, line 102 could be characterised as a claim; lines 103 and 106 perhaps as a rebuttal; but lines 104 and 105 do not appear to fit within an argumentation framework. As a result this passage would probably be discarded or at best regarded as an uninteresting level 1 argument.

However, we claim that small parts of discourse like this are crucial as persuasive arguments towards a tentative understanding that keeps the discourse going. In our framework we characterise line 103 as an other-oriented claim, line 104 as an other-oriented prompt in question form, line 105 as an other-oriented prompt in statement form, and line 106 as a self-oriented claim (since it affirms the student's own question from line 104).

In this way, we were able to analyse and give meaning to almost every part of the PTs' discourse.

5.9 Using the framework to compare different episodes

One useful aspect of using this framework to analyse episodes of discourse is that it provides a useful way to compare episodes. By looking at the discourse matrices we can make judgements about the type of discourse that is taking place. For example, the distributions of 'dots' in Table 5.11, Table 5.14 and Table 5.16 are quite similar. This suggests that the discourse may be of a similar nature, and this is borne out when checking the transcripts. In each of these episodes, PTs were mostly listing the physical quantities they were trying to use to explain the phenomenon. In episode 1, these quantities were temperature and, indirectly, the number of molecules; in episode 4, temperature and pressure; in episode 7, temperature, volume and pressure. The following three excerpts are similar: compare from episode 1

> *2. Barbara: The pressure in the tank…*
> *3. Jim: … Is less than the pressure outside*
> *[…]*
> *8. Jim: So if [the valves] had been left open…*
> *9. Denise: … there would have been air.*

to, from episode 4,

> *37. Denise: It says though the valves were disabled and removed, does that mean they are not there?*
> *38. [long gap]*
> *39. Barbara: Heated air has more pressure than unheated air so there is more pressure in the tank*
> *40. Jim: Than the outside*
> *41. Barbara: Than the outside*
> *42. Barbara: It has to beat the pressure outside*

and, from episode 7,

> *98. Denise: So surely it moved closer because if you are using a steam cleaner you are adding more molecules into it.*
> *99. Barbara: Well in the general picture we know that the… we know there is more pressure because we are adding in heat*
> *100. Jim: The change in temperature is causing it to get smaller isn't it?*

During these episodes, the PTs were lining up various relevant physical quantities. This also explains that most of the lines in these three episodes were statements, claims and data. This indicates that the PTs were not yet elaborating on each other’s ideas, or collaboratively constructing knowledge. They were talking about physical quantities, but not much about how they relate to each other, nor were they sense-making in a more general sense.

Likewise, Table 5.19 and Table 5.20 reveal that episodes 11 and 13 are similar in terms of discourse, comprising almost excusively elements of argumentation in the form of statements and responses, and non-argumentation elements in the form of questions. In both cases, the PTs were attempting to link different elements of physics together. Note that our framework elucidates the role of non-argumentation utterances that keep the discourse going, and allowing the group to develop their understanding.

Finally, evidence of the framework being a useful tool for comparison can be seen by comparing Table 5.13, Table 5.15 and Table 5.17, although the similarities are perhaps not as strong as in the previous two cases. When looking at the transcripts, we did find some similarities in the discourse. In episodes 3, 6, and 9, PTs are starting to extract the relevant details from the video of the imploding tanker that are needed to form a physical model of what happened. In doing so, they also start to think about things at a microscopic level. Here, they have moved beyond coming to an understanding of the task, instead moving on to talk about the phenomenon. By just looking at the tables, we can see that in these episodes roughly one-third of the lines have been coded in the non-argumentation portion. As well as this, codes are evenly split between statements and responses, indicating that PTs are beginning to build on each other's ideas in order to understand the phenomenon. This can be seen further when we look at excerpts of the transcripts for both of these episodes. In Episode 3, PTs move from talking about pressure to talking about steam and air:

24. Barbara: They steam cleaned the inside, they closed it, the steam stayed
25. Jim: …and when they opened…
26. Jim …and when they opened it, it hit normal air…and collapsed

In Episode 6, PTs are again talking about things at a microscopic level. They are also beginning to make links between molecules, their movement and pressure.

Finally, we consider Episode 13 in some detail, since it indicates how far the group of PTs have progressed. It is therefore an interesting passage to look at in terms of the Learning Cycle. It demonstrates how over the course of 50 minutes, PTs were able to arrive at a somewhat coherent, albeit incomplete, shared explanation of the phenomenon. In this Episode, 93% of the lines are coded as other-oriented, an indication of the shared nature of the discourse and the explanation. The full transcript of the episode is included below.

228. Denise: So we'll say that because it was left overnight the temperature decreases [pause]
229. Denise: As the container was left overnight the temperature decreased along with the pressure
230. Jim: See, if we use this formula, then we can kind of work out if the pressure increases if the other two do. Temperature and pressure are proportional so if temperature increases or if the pressure increases the temperature will increase too.
231. Barbara: Yeah
232. Jim: So therefore the volume is going to increase. What happens if…?
233. Denise: They are all proportional or are they not, because, if you…
234. Jim: So you think temperature is going to increase as well if pressure and volume increase?
235. Denise: Well temperature will increase anyway if the volume… the pressure increases
236. Jim: … So once one of them increases they all increase?
237. Denise: I think so.
238. Jim: So that's why it gets smaller because
239. Denise: Because it's starting to decrease then.
240. Jim: Is the temperature going to rise?
241. Denise: It is but then it is left overnight to cool… And it starts to decrease a little bit.
242. Jim: How does to cool?
243. Denise: They turn the cleaner off. We were told because it's left overnight it will cool.

5.10 What has emerged from Learning Cycle 3 and Research Cycle 3A

One of the main questions that Research Cycle 3B wanted to address was if it was possible to characterise the discourse of PTs using the framework discussed in Section 5.3. The analysis above showed that the framework provided a useful lens for analysing the discourse of a group of PTs as they constructed an explanation of a scientific phenomenon.

We found that the conceptual framework that combined argumentation, sense making and transactive turns, allowed us to characterise episodes of discourse in meaningful ways. Construction of discourse matrices helped us establish simliraties and differences between different episodes. The framework was applied to an open inquiry activity in which PTs had to explain a physics phenomenon that required quite intricate reasoning. We found three sets of episodes in which similar fractions of discourse were devoted to statements, questions, and responses on the one hand, and argumentation and non-argumentation utterances on the other. They appeared to correspond to similar types of discourse. We found that discourse dominated by statements and otherwise argumentation-related utterances corresponded to PTs listing relevant notions from physics without trying to link them. We found that discourse that in which PTs did try to make links was characterised by a very different distribution, made up by argument-related statements and responses and non-argument related questions in roughly equal measures. Three episodes in which the discourse was primarily about extracting the relevant physics from a well-understood scenario were also found to be similar in terms of elements of discourse.

3B.3. How does this analysis inform future design cycles, especially with regards to PTs' Professional Vision?

Because we were able to classify PTs' discourse in a meaningful way using the framework outlined in Section 5.3, the Cycle has the potential to be very useful in informing future cycles. While it is difficult to make explicit claims about PTs' Professional Vision based on analysing the discourse alone, the Cycle was very useful in the development of the Design Experiment.

As mentioned in Section 5.5, as part of the workshop PTs were asked to write a semi-structured reflction on the workshop. An informal analysis of theses showed that the workshop has potential to give further insights into PTs Professional Vision. Similar to Cycle 1, some PTs were still concerned about factual knowledge. For example, one PT stated that

> *"I am still unsure of how exactly the tanker imploded. I am also unsure of what topic this falls under so that it would be relevant in a classroom situation."*

Another PT identified how using an approach similar to that in the workshop could be useful for developing students' reasoning skills.

> *"I was able to see how to teach the topic in a way that stimulates students' thinking which is often better than given them the information. I learned that a class that consist of a large amount of student contribution is more effective than on which the teacher does everything."*

5.11 References

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Chapter 6 Conclusions

This chapter summarises the results for each of the design cycles, the contributions made to the field of science education, and discusses the direction that future work in this area could take.

6.1 Outcomes of the Design Experiment

6.1.1 Design Cycle 1

As part of Learning Cycle 1, PTs participated in 5 three-hour workshops. In line with our local instruction theory, PTs first carried out and then critiqued inquiry-based activities designed for the Junior Cycle Science classroom. A four-step analysis framework was developed. Through an iterative process relevant quotes from the critiques were selected individually by a team of four researchers on a group-by-group, week-by-week basis. In-depth discussion of the initial claims made by the individual researchers allowed us to first revise the claims, and then reduce them to a set of summary claims representative of the entire cohort of PTs on a week-by-week basis. Final claims were arrived at by reconsidering the summary claims in the light of the PTs' Professional Vision elicited in other weeks. This analysis of the PTs' critiques of these activities, which were mostly guided in nature, allowed us to make claims about the PTs' Professional Vision of IBSE.

In an Irish context, this study was the first of its kind to explore in depth the Professional Vision of PTs, though other studies have looked at the development of Irish PTs in terms of their PCK (Lehane, 2016). Like Lehane, we found that PTs had a superficial understanding of the goals of IBSE. We found that they were able to highlight some important aspects of IBSE, but rarely did evidence emerge of PTs giving deeper meaning to these highlighted aspects. We found that PTs classified science teaching in three broad ways: rote learning, guided inquiry and open inquiry. By the end of Learning Cycle 1, the PTs' Professional Vision indicated a strong focus on the correctness of students' knowledge and procedures. These results were similar to results reported in existing literature, and it is reassuring that we obtained a similar picture by using a different technique (experiencing and critiquing inquiry activities compared to e.g. video analysis). Although the existing literature reported on PTs in different cultures, the challenges they faced when learning about IBSE were similar to what we found in an Irish context (e.g. Crawford, 2007); Lotter, Harwood, & Bonner, 2007)).

Design Cycle 1 also served to inform the development of Cycle 2. The results allowed us to transition from mostly probing our PTs' Professional Vision to also trying to broaden and shape it.

6.1.2 Design Cycle 2

In Learning Cycle 2, PTs again took part in 5 three-hour workshops. Three of the workshops from Cycle 1 were retained, but the first two workshops were replaced. The first of these new workshops allowed PTs to experience a new university-level physics topic through guided inquiry. The PTs critiqued this activity in the same way as they did the Junior Cycle activities. In this way, we aimed to let PTs experience the process of learning through IBSE, which allowed us to broaden their Apprenticeship of Observation. This in turn enabled us to investigate if the focus on correct knowledge and procedures was a direct result of their Apprenticeship of Observation up to that point.

In the second new workshop, PTs carried out an open inquiry activity that was suitable for use at both university and Junior Cycle level. In the first part of this Pressure workshop, PTs were asked to explain in detail a somewhat complex phenomenon. In the second part of this workshop, they analysed video clips from an Irish classroom in which the topic of pressure was taught over 9 classes. This series of classes started with the same video the PTs had watched, but the classes following this were adapted and activities designed as the need arose. PTs watched 50 minutes of edited footage from this series of classes and reflected on this video footage.

As a learning cycle, this iteration of the DBR was deemed an improvement since it introduced the PTs to new aspects of IBSE – learning material for the first time through IBSE, and a vicarious experience of an open inquiry class. As a research cycle however, this iteration turned out to be important mostly as a precursor to Design Cycle 3.

6.1.3 Design Cycle 3

Design Cycle 3 was split into two research cycles, Cycle 3A and Cycle 3B. The learning trajectory for Cycle 3 was similar to that of Cycle 2, the only difference being that a continuous half-hour video of teaching based on the same phenomenon, but taught in a US classroom, was used. In Learning Cycle 3, the PTs were able to experience and reflect on inquiry, along with being able to learn new content through inquiry. They also got to experience teaching through inquiry vicariously through the use of video footage.

The aim of Research Cycle 3A was to examine the highlighting and coding practices of groups of PTs as they analysed video footage of an open inquiry activity in the classroom. Five themes that were commonly highlighted as good teaching or important student ideas were found. On the one hand, we found that the PTs generally highlighted sensible episodes, but rarely give evidence of if and how they coded these episodes. On the other hand, almost all groups showed an emerging appreciation of the collaborative nature of constructing knowledge in open inquiry, and some groups evaluated the quality of some of the students' statements. This suggests that video analysis helps elicit that some PTs are developing the ability to think like an IBSE-oriented teacher in a constructivist classroom, as found in the literature e.g. by Sherin & van Es (2005) for US pre-service mathematics teachers. I found that the coding and highlighting by groups of PTs from an Irish university and those from a US research university were broadly similar. This suggests that despite some likely minor differences in school cultures between the two countries, the Apprenticeship of Observation PTs bring to a university course is broadly similar. This is in agreement with the literature, which finds that science teaching and learning in most "western" countries is quite similar and faces similar challenges (see e.g. Rocard et al. (2007) and the US National Research Council (2000)).

Research Cycle 3B investigated if it was possible to characterise the discourse of a group of PTs as they participated in an open inquiry activity. To this end a new framework combining argumentation, sense-making and transactivity was developed. This new framework allows us to characterise most aspects of PTs' discourse, unlike previous frameworks such as TAP (Erduran et al., 2004) which were designed to look at argumentation only. Furthermore, within this new analysis framework we found that the construction of discourse matrices comprising six elements of discourse and six types of transactivity helped establish similarities and differences between different episodes of student discourse. We found that episodes in which similar fractions of discourse were devoted to particular elements of discourse and transactivity correspond to similar types of sense making and developing scientific understanding. Moreover, we were able to ascertain that non-argument-related elements of discourse such as prompts and clarifications were of great importance in keeping discourse going, especially when linking together different physics concepts and trying understanding a scenario, which would likely not attract much interest in a purely argumentation-based framework such as Toulmin's Argumentation Pattern (Erduran, Simon and Osborne, 2004). Finally, we found that in a teaching setting quite similar to a typical classroom situation, in which a teacher can visit each groups for perhaps three relatively short periods of time, the PTs were able to make significant headway in constructing knowledge that was getting close to the normative understanding.

6.2 Eliciting and Broadening PTs' Professional Vision

In this work, I set out to answer the research question: How can the Professional Vision of PTs be elicited and broadened effectively within the module IBSE101? The development of a set of five three-hour workshops in which PTs experience and critique different forms IBSE in different ways has allowed us to achieve this. In three of the workshops PTs experience mostly guided inquiry activities at secondary school level. In one workshop, they had a vicarious teaching experience of an open inquiry activity. In the fifth workshop, they experienced learning a new topic through guided inquiry, possibly for the first time. Through our analysis of the PTs' highlighting and coding we were able to establish that their Professional Vision of IBSE may be both elicited and broadened.

6.3 Limitations of the Study

There are some limitations to this research which need to be considered if future research cycles were to be implemented. As a result of Cycle 1, we have made claims about PTs Professional Vision, and carried these through other cycles. However, PTs were, at this stage, still at quite an early stage of their teacher education. For this study it was not practical to undertake a longitudinal study of the initial group of PTs over a longer period of time. However, for future research (Section 6.4) it would be interesting to profile a group of PTs over the course of their teacher education to examine how this module (and others) shape both their Professional Vision and their Apprenticeship of Observation as they progress towards becoming a qualified teacher.

Research Cycle 3B explored in detail the characteristics of a group of PTs as they worked towards explaining a scientific phenomenon. Like in Cycle 1, for this study it was only practical to analyse the discourse of one group of PTs. Comparing this to the discourse characteristics of other groups could provide more insights into the framework. It would also be useful if future cycles were to include activities where PTs could use this framework to analyse the discourse characteristics of students.

6.4 Potential Future Cycles

As IBSE101 progresses, further Learning and Research Cycles could be developed. If the Design Experiment moved to Cycle 4, there is a lot of potential to build on the outcomes of Cycle 3. The workshop included in Learning Cycle 3 showed that PTs have the potential to construct an explanation of a scientific phenomenon as they worked as a group. One possible change for Learning Cycle 4 could be to allow PTs to use a similar framework to analyse student discourse, allowing them to make judgments on the quality of both sense making and the explanations.

For Research Cycle 4, I recommend further refinement of the methodologies used, especially the analysis framework developed in Research Cycle 3B. In order for this to become a useful tool for science education researchers it is necessary to use the instrument with other groups, including PTs, science students, and in-service teachers.

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Appendix A Workshop Material for Cycle 1

Appendix A Workshop Material for Cycle 1

Name: ____ **Class:** ____________________

Experiment: Mirrors

Use the equipment provided to investigate how light reflects from a flat mirror. Describe and report any measurements you make.

Experiment: Mirrors

In this experiment you investigate how light reflects from a flat mirror.

1. Put a sheet of paper on the table. Use the laser pointer to obtain a narrow beam on the sheet of paper. Now put the mirror in the path of the light beam. Describe the effect the mirror has on the beam.

____

____

____

____

____

2. Put the mirror on the handout. Get the beam to hit the mirror at the point where lines A, B, C and D meet. Then adjust the beam of light until it turns back on itself at the mirror.

   Draw this line – it is called the *normal*.

3. Investigate what will happen to the beams of light that shine along lines A, B, C and D when they shine on the mirror. Use a pencil and ruler to mark the light on the handout when it is shining away from the mirror.

____

____

____

____

____

____

4. Use a protractor to find the angle between the normal and each of the lines A, B, C and D.

   Also measure the angle between the reflected light and the normal in each case.

   Complete the table below.

Table 1: The angle of reflection for each angle of reflected light.

	angle of light to mirror	angle of reflected light
A		
B		
C		
D		

5. Does the reflected light seem to be at an angle *greater than, less than,* or *equal to* angle of the light shining on the mirror?

____
____
____
____
____

Describe how you could predict where a light beam is reflected if you know where the normal of the mirror is, and what angle the incoming beam makes with the normal.

____
____
____
____
____

Part 1: Measurement and units (40 mins)

Keywords: measurement, width, length, mass, unit, standard units, unit conversion, rank

- Question students on what they believe a unit to be. Guide their suggestions and ideas to come up with the explanation that a unit is something we can use to represent a measurement or describe a magnitude.
- Split students into groups of 3 or 4 to complete Activity 1.

Activity 1: The Standard Unit

Measure the width of the room using your feet and record your answer.

Did everyone in the group get the same answer?

Why do you think this is?

Use the metre stick to measure the width of the room in cm, and record your answer.

Did everyone in the group get the same answer?

Why do you think this is?

Why do you think it is important to have a standard (common) unit?

- Discuss with the class the answers students gave for the last question. Mention *e.g.* speed signs and the speed dial in a car, or Mars Lander crash, to reiterate the importance of a standard unit.
- Concentrate on length units for Activity 2. As revision before starting the Activity get students to recall the standard units for length (mm, cm, m, and km) and the conversions (10 mm = 1 cm, 100 cm = 1 m, 1000 m = 1 km). Students are to complete Activity 2 individually.

Activity 2: Unit Conversion

I have three pieces of string. String A has a length of 0.5 m, string B has a length of 25 cm, and string C has a length of 200 mm.

1. Suppose you just look at the numbers and not at the units. Rank the strings from longest to shortest.
2. Now consider numbers and units. Again, rank the strings from longest to shortest.
3. Compare the two rankings. Which ranking is correct?
4. When comparing measurements, is it enough to just look at the numbers?

- Discuss the answer given to the last part of Activity 2. Pose the question that 'if we need to have measurements in a common unit to be able to compare them, why would we not just have one unit (e.g. just m) and not use cm, mm or km?'
- As an introduction to Activity 3 revise (from primary curriculum) standard units and conversions for mass and time in a similar way to the introduction to Activity 2.

Activity 3: Homework (start in class if time permits)

Show workings for each of the following:

1. It takes Kevin 6 steps to walk 3 m, but only 4 steps to jog 3 m. He first jogs for 60 m and then walks for 30 m. How many steps does he take?
2. Elena walked a distance of 800 m. Amy walked a distance of 1.2 km. Seán walked a distance of 90,000 cm. Bronagh walked a distance of 1,100,000 mm. Which student walked the furthest?
3. Sorcha, Maria and Nicole all started their homework at the same time. It took Sorcha 1.5 h, Maria 93 mins and Nicole 1 hr and 1,860 s. Who finished first?
4. A shopper wants to put six items in a cardboard box. The box is big enough to fit everything in, but it can only hold up to 4 kg. There are 3 packets of butter, each with a mass of 454 g, 2 bags of sugar, each with a mass of 0.5 kg, and a bag of apples with a mass of 1.326 kg. Can the shopper put all items into the cardboard box?

Part 2: Area (40 mins)

Keyword: area

- Split students into groups of 3 or 4 to complete Activity 1.
- Give each group one 24 cm × 12 cm laminated sheet, and a set of either 2 cm × 2 cm, 3 cm × 3 cm, 4 cm × 4 cm, or 6 cm × 6 cm squares
- Have 5 cm × 5 cm square sets ready for handing out later

Activity 1

1. How many squares cover the large sheet? Record your answer here: _______
2. Swap a set of squares with another group. How many squares cover the large sheet now? Record your answer here: _

   Are your answers the same as before? _____

   Do you think one answer is better than the other? Explain.

3. Explain how you can get different numerical answers but that both answers are correct.

Activity 2

1. Form a group with at least 1 more student. Go to the website http://www.shodor.org/interactivate/activities/AreaExplorer/. Determine the area of a few shapes, and check your answers. (Click the "Draw New Shapes" button to go to a new shape.)
2. Now tick the "Only Draw Rectangular Shapes" box and draw a new shape. Determine the **area** by counting the total number of squares. Also count the number of squares on the length of the shape and the number of squares on the width of the shape. Write down your answers in the table on the next page, in the row marked "Shape-1".

   Repeat this for at least 3 more shapes.

	area (number of squares)	number of squares along the length	number of squares along the width
Shape 1			
Shape 2			
Shape 3			
Shape 4			

3. Can you and your partner see a relationship between the numbers in each row? If so, write it down.

   Explain in words how you can calculate the area of a rectangle if you know its length and width.

Activity 3: Whole class discussion

- Discuss with the class the need for standard units. A possible pathway is to ask students for a clear complete way of describing the area, e.g. 8 blue squares or 24 green squares; etc.
- Link back to standard unit for length. Introduce the need for standard units like cm^2, m^2, mm^2.
- Get students to predict how many mm^2 there are in 1 cm^2.
- Overhead slide on converting mm^2 to cm^2. Get students to take notes, and discuss the notes they have taken.

Activity 4: Homework

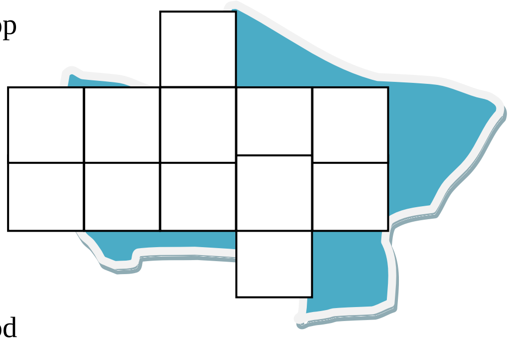
1. A shape is 30 cm long and 10 cm wide. What is its area? Show your work.
2. Determine the area of your book in cm^2. Record how you did this.
   Do you think another student reading this would be able to understand your method and do it for their own book? If not, change your answer until you think it is understandable to somebody else.
3. What is the area of the front of a cereal box? What is the area of the side of a cereal box? Show your work like you did in question 2.

Part 3: Area and volume (40 mins)

Keywords: area, volume, irregular, estimate

Activity 1: The area of irregular shapes

1. Explain why you cannot find the area of this shape by multiplying length and width.

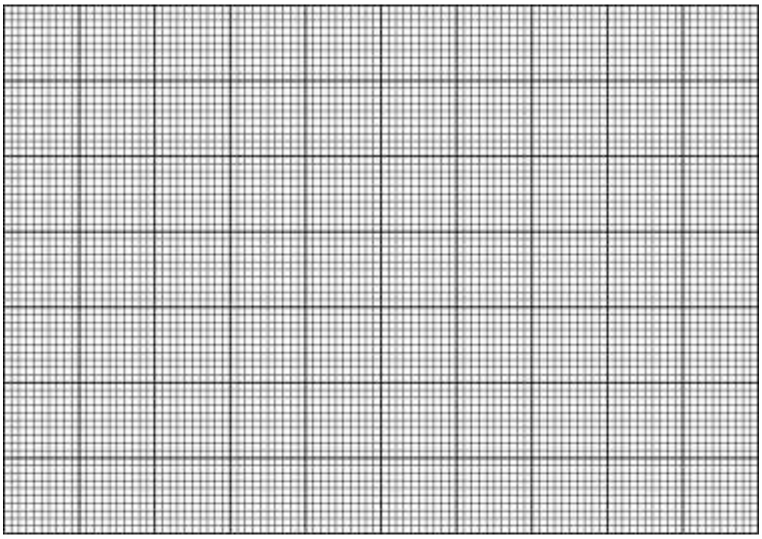


2. Somebody put a number of 1 cm by 1 cm squares on top of the shape.

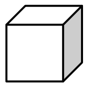
   Estimate the area of the shape.

3. How could you use graph paper to get a really good estimate of the area of a shape? Explain carefully what you would do.

4. What is the area of one large square in the graph paper below?
   And of a small square?
   Use the graph paper to find the area of your thumb. Describe clearly what you did.



Activity 2:



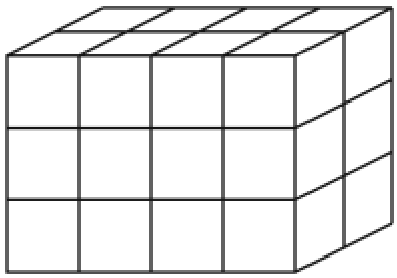
1. What kind of shape is this?
2. Measure the **area** of one side. How did you do this?

Area is a 2-dimensional idea, so it only deals with flat things. The shape is 3-dimensional. We say it is a **cubed unit**.

3. How many cubed units make up this cube? Be careful as you count. You cannot see all of the units.

Answer: _______________

How many cubed units are in these blocks?



Answer:_____________ Answer:_________________

Volume is the amount of space an object takes up. You can measure **volume** by counting the number of cubed units that fit

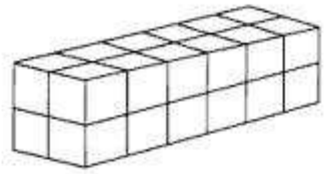
4. What is the **volume** of each of the blocks in Question 3?

   Left block: ________________; Right block: ______________________

   Is the size of the small cube units in each of the blocks shown the same? _______________.

As with **area**, we need standardised units of volume. If the small cube measures 1 cm on each side, then its volume is described as “one centimeter cubed”. This is written as 1 cm^3.

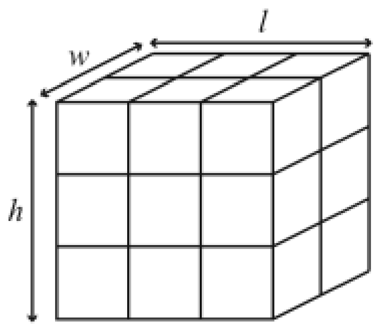
5. Each of the small cubes has a volume of 1 cm^3. What is the total volume of each of these shapes?



Answer:_______________

Answer:__________________

6. For the shapes shown below record (a) their volume, if each small cube has a volume of 1 cm^3, and the measurement of (b) their length, (c) their width and (d) their height.

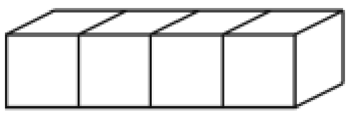


Volume:

Length:

Width:

Height:



Volume:

Length:

Width:

Height:

7. How could you calculate volume from the length, width and height? Tick which of the following options you think is correct. Use the information given above to help you discover the correct answer:

   a. $V = l + w \times h$

   b. $V = l - w + h$

   c. $V = l \times w \times h$

   d. $V = l + w - h$.

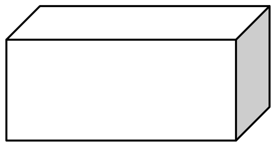
   Check your answer with your teacher.

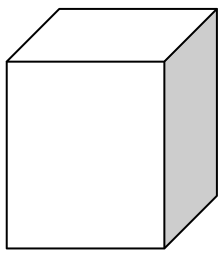
Activity 3: Homework

1. What is volume?

2. What is the volume of a box that has a height of 6 cm, a width of 2 cm and a length of 3 cm?

3. What is the volume of the blocks shown? (Use a ruler, show all your work, and give your answer in cm^3.)



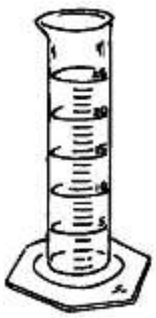


Part 4: The Volume of Irregular Objects (40 mins)

Keywords: meniscus, volume, overflow can, graduated cylinder, beaker.

Activity 1

You need a block, a pebble, a stone, a graduated cylinder, a beaker, and an overflow can.



graduated cylinder

overflow can

1. Measure the volume of the block. List all measurements made and show all calculations.

2. Put water into the graduated cylinder so that the bottom of the **meniscus** is at the 30 ml mark. (Note: 1 ml is the same as 1 cm^3).

3. Lower the block into the graduated cylinder. Read and record the mark at the new water level.

   New water level mark = ___________.

4. What is the difference in ml between the two readings? Record your answer.

   Answer:

5. Compare the answer you calculated in question 1 to the answer you got in question 4. What do you notice?

6. Use what you have learned to measure the volume of the pebble. In your lab book write a report on what you did under the usual headings.

Activity 2

Use the block, a graduated cylinder, a beaker, and an overflow can.

1. Put the beaker under the spout. Fill the overflow can with water until a little water runs into the beaker. Now empty the beaker and put it back under the spout.

2. Lower the block into the can. Collect the overflowing water in the beaker. Use the graduated cylinder to find the volume of the overflown water.

3. Compare this answer to the answer calculated in questions 1 and 4 of activity 1. What do you notice?

4. Use what you have learned to measure the volume of the stone. In your lab book write a report on what you did under the usual headings.

Activity 3: Homework

1. A student was asked to measure the volume of a wooden toy. When she lowered the toy into an overflow can, it floated. Some of the toy remained above the water. 25 cm^3 of water overflowed.

   Is the volume of the toy 25 cm^3? Explain your answer.

   If your answer is “no”, how could the student measure the volume of the toy?

Part 5: Why some things float in water, and other things sink (80 mins)

Keywords: float, predict, test, record, method, with the aid of, density

Collect an apple, a pear and a potato from the trolley. You can use any other equipment from the trolley that you need.

1. Why do you think some things float and some things sink?

2. Find, and record the mass of an apple. _________________.

   Find, and record, the mass of the pear. _________________.

   Find, and record, the mass of the potato._______________.

   Predict whether the apple, the pear and the potato will float in water. Refer to your answer to question 1.

Object	Will float	Will not float
Apple		
Pear		
Potato		

Explain your predictions here:

3. Test whether the apple, the pear or the potato float and record your answers in the table below.

Object	Tick here if it floated	Tick here if it sank	Was your prediction correct?

4. Cut off a tiny piece of potato, as small as you can cut. Predict whether this tiny piece will sink or float.

I predict that this small piece of potato will float. ☐
I predict that this small piece of potato will sink. ☐

Drop the tiny piece of potato into a beaker of water. Tick the box to show what happened.

The small piece of potato floated. ☐
The small piece of potato sank. ☐

5. Look at your answer to question 1. Do you think the answer you gave there is correct? If not, explain why it is not correct, and try and improve your answer.

6. Measure and record the volume of the apple, the pear and the potato. With the aid of a diagram, explain how you did this and record your results in the table.

Object:	Volume in cm^3
Apple	
Pear	
Potato	

7. Find the **mass** of 100 cm^3 of water. Explain how you did this is the space below.

The mass of 100 cm^3 of water is _________

What is the mass of 1 cm^3 of water? Show your work.

8. Complete the table below. Use your results from question 1 and from question 7. To complete column three, calculate the mass of 1 cm^3 of the apple, the pear and the potato.

Object description	mass (g)	volume (cm^3)	mass of 1 cm^3 (g)
Apple			
Pear			
Potato			

Is the mass of 1 cm^3 of an apple *greater* or *less* than the mass of 1 cm^3 of water?

Is the mass of 1 cm^3 of a pear *greater* or *less* than the mass of 1 cm^3 of water?

Is the mass of 1 cm^3 of a potato *greater* or *less* than the mass of 1 cm^3 of water?

Density is a measure of how much mass is contained in a given unit of volume of a substance *e.g.* 1 cm^3.
If one object has more mass in a unit volume than another, then

Is the density of the apple *greater* or *less* than the density of water?

Is the density of the pear *greater* or *less* than the density of water?

Is the density of the potato *greater* or *less* than the density of water?

9. Examine your results on which object floated and which sank (question 3). Read your statements on density (question 8). How could you predict if an object will float in water?

Lesson 6: Predicting if an object will float or sink (40 mins)

- **Density** is a measure of how much mass is contained in a given unit of volume.
- **Density** is found by dividing the mass by the volume.
- 1 cm^3 of water has a mass of 1 g.
- The **density** of water is 1 g/cm^3.

1. You are given some cubes. Each of the cubes is made from a different material. Number the cubes 1, 2 and 3.

2. Find the **density** of each of the cubes. In your lab book write a report on **how** you found the density and show your calculations and results. Then complete the table below and predict whether each cube will sink or float in water.

	density	prediction	was your prediction correct?
Cube 1			
Cube 2			
Cube 3			

3. Test your prediction and complete the final column. If your prediction was correct, explain **why** you made this prediction. If your prediction was incorrect, can you try to explain why your prediction was incorrect?

4. Given two iron cubes and two aluminium cubes of the dimensions and masses shown, calculate the density of each cube. Use your calculator.

Material	Length (cm)	Width (cm)	Height (cm)	Volume (cm^3)	mass (g)	Density (g/cm^3)
Aluminium	3	2	2		32.4	
Aluminium	2	4	2		43.2	
Iron	3	2	3		142.2	
Iron	2	2	2		63.2	

DENSITY IS A PROPERTY OF A SUBSTANCE. It REMAINS THE SAME NO MATTER WHAT THE MASS OR VOLUME OF THAT SUBSTANCE.

Activity 2: Homework

1. The mass of 1 cm^3 of aluminium is 2.7 g. What is the density of aluminium?
2. If the mass of 1 cm^3 of aluminium is 2.7 g, what is the mass of 4 cm^3 of aluminium?
3. If a piece of aluminium has a volume of 3 cm^3, what is the mass of this piece? (Recall that 1 cm^3 has a mass of 2.7 g)
4. Before the tetra pack was invented milk was delivered and sold in bottles. It was usual to shake the bottle before opening. Find someone who remembers these milk bottles and ask them **why** it was important to shake the bottles before opening. Their answer should help you with the following question:

Which is more dense: milk or cream?

Part 7: Challenge (40 minutes)

Arrange these materials in order of increasing density: raspberry; oil; blueberry; water; apple; lego; styrofoam.

Write a report on what you did. Make sure to include diagrams and tables where appropriate.

Tutorial: Pushes and pulls

Forces and shapes

1. Take a piece of blu-tack and place it on the bench.

   Can you change the shape of the piece? In the space below draw the blu–tack before you started and draw its new shape.

2. Describe what you did to change the shape of the blu-tack.

3. Pictures can be used to represent actions. In the space below draw a picture of what you did to change the shape of the blu-tack.

4. Make a list of four other actions you could have used to change the shape of the piece of blu-tack.

A force was applied to the blu-tack.

A force can cause a change of shape.

5. Look at the actions described in Question 4. Most forces are either a PUSH or a PULL.

Decide which of the actions listed are a PUSH and which are a PULL.

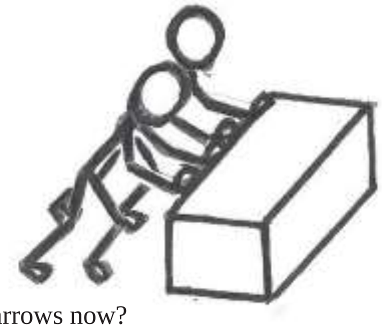
Most forces are pushes or pulls.

6. Arrows can be used to represent forces. Draw an arrow to represent the push force the boy exerts on the box.

As the boy pushes the box it slides along the ground, and it speeds up a little.

A force can change how an object moves.

7. While the box is moving, a friend comes over to help. He pushes as hard as the first boy. Draw one or more arrows to represent the PUSH force on the box now.

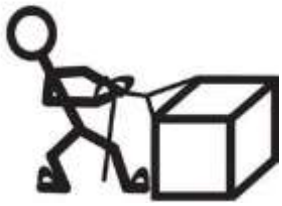


What is different about the arrows now?

Will the box move the same as when just one boy was pushing? Explain your answer.

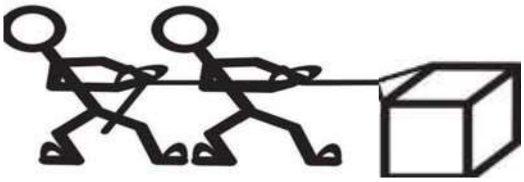
8. The first boy now pulls on the rope as hard as he was pushing the box before.

Draw an arrow to represent the PULL force on the box.



Remember: a force can change how an object moves. What can you say about how the box moves now?

9. Draw one or more arrows to represent the PULL force on the box now. Each boy pulls as hard as before!



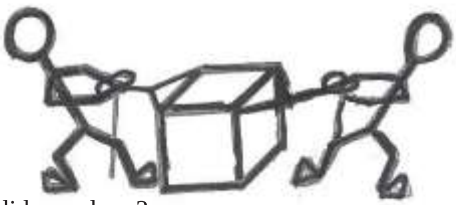
Is the PULL force any different from before?

Are the arrows different when one or two boys are pulling? If it is, explain WHY there is a difference.

Do you think the box will move? If you think the box will move, will it move the same as in Question 8?

Explain your answer.

10. Draw arrows to represent the PULL forces on the box. Each boy pulls as hard as the other!



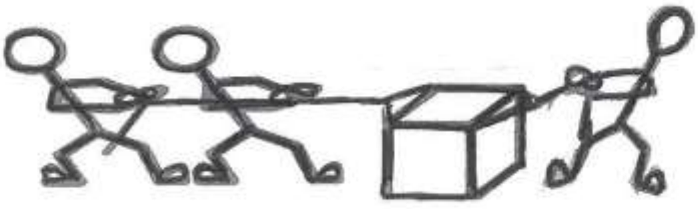
How many arrows did you draw?

Explain in what way the arrows are the same, and how they are different.

Do you think these pull forces change how the box moves?

Explain your answer.

11. Draw arrows to represent the PULL forces on the box now.



Do these pull forces change how the box moves?

Explain your answer.

A Force can change how an object moves.

If a Force does not change how an object moves,
then there must be another force of equal size acting against it.

Homework Question

1. Consider the two situations shown below.

Use force arrows to help explain why and how the two boxes move differently.

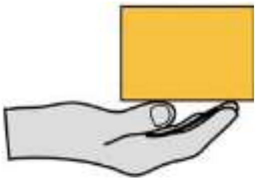
Tutorial: Weight

1. From now on, we will represent a bigger force by a longer arrow.

   Compare this to the representation you used. If they are different, can they show the same things?

   If a force was twice as big as another, how would you show that in the arrows?

2. A man balances a box on his hand as shown.



   What happens to the box if the hand is removed?

   Does the box move differently when the hand is removed?

   What makes an object move differently?

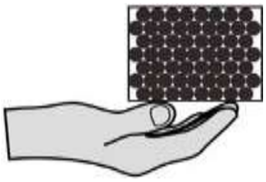
3. Draw an arrow to represent the force acting on the box when the hand is removed.

   What do you think causes this force?

   Draw an arrow for the force of the hand on the box (before you removed it). Explain how you drew it.

4. The man now holds the same box filled with marbles as shown.

Draw an arrow to show the force acting downwards (i) before, and (ii)



after the hand is removed.

Are the forces bigger, smaller or the same as in Question 2? Explain.

5. An astronaut holds the same box, filled with marbles, while standing on the moon.

What happens to the box when the astronaut removes her hand?

Does the box move differently?

Draw an arrow to represent the force acting on the box when the astronaut's hand is removed.

Is your arrow the same as in Question 3? If the arrow is different explain WHY you think it should be different.

WEIGHT is the force that makes the box move when the hand is removed.

WEIGHT depends on the mass of an object.

WEIGHT is the force of
gravity,
which is greater on Earth than on the Moon.

weight = mass x *g* (on Earth: weight in N = mass in kg x 10)

Homework Questions

1. Weight is a force, so what unit is used for weight?

2. A box has a mass of 5 kg. What is its weight on Earth?

3. A box is hung from a spring as shown.

If the weight of the box (which is a force) is acting downwards, why does the box not start to move downwards?

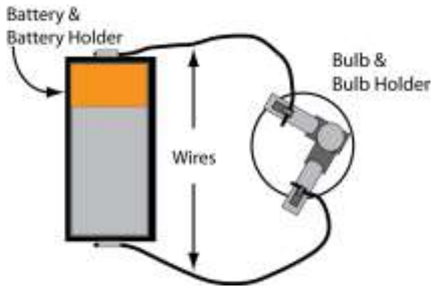
Mandatory Experiment: Electric conduction

In this experiment, you will investigate how different materials affect the brightness of a bulb in a simple electric circuit.

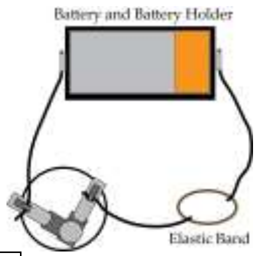
1. Take a battery holder, a battery, a bulb holder, a bulb andtwo connecting wires and set up the circuit shown at right.

   Does the bulb light?

   ____



2. Suppose you would place the materials you're given, one by one, in the circuit as shown. In the table below, write whether you think the bulb would light or not. **Do not carry out the experiment yet.**



What do you think?	
Material	**Bulb will light (Yes/No)**

3. Insert each of the materials individually into the circuit as shown in the diagram above. Take note of your observations by filling in the table below.

	Results	
Material	**Bulb lights**	**Bulb doesn't light**

4. Compare your results in Question 3 with your ideas from Question 2. Which of your ideas were correct, and which were incorrect?

____

____

__

You have seen that different materials have different effects on bulb brightness. This leads us to the two new terms based on our observations. The objects that let the bulb glow are called **conductors**. The objects that make the bulb go out are called **insulators**.

5. Insert some of your own objects into the circuit to test if they are conductors or insulators. Tick the appropriate box in the table below.

Object	**Conductor**	**Insulator**

6. Do the conductors that you have seen so far have anything in common?

____

____

__

In the last few steps we separated a number of materials into groups of conductors and insulators. We now look at some other conductors and compare their effects on bulb brightness.

7. Set up a circuit which allows you to investigate the following hypothesis:

"Copper wire is a better conductor than nichrome wire."

Plan your investigation below. Make sure you include a diagram of the set-up you think you will use. (**Hint:** If an insulator makes a light bulb go out and a good conductor makes it light, how could you identify a not-so-good conductor?).

Discuss if you have designed a fair test. If not, what would you need to make the test a fair one?

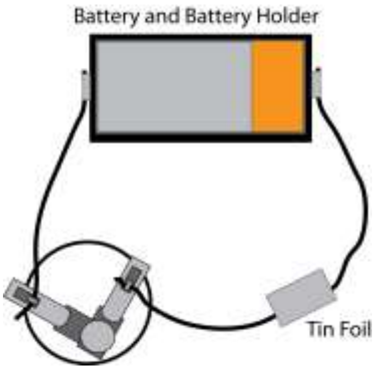
8. Check your plans with your teacher. Do not change your answers to part 7; instead, describe how you carried out your investigation, and the results you got, in the space below. Draw a new diagram of the set-up if you need to.

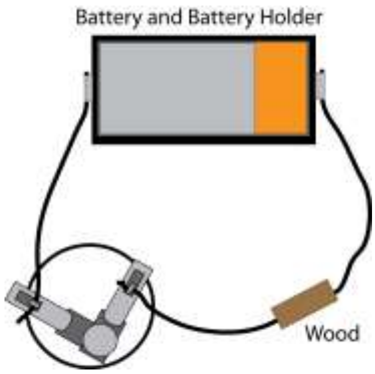
9. We can rank materials by how good an insulator they are. This property is called the material's **resistance**. Which has a higher resistance: a piece of copper wire or an elastic band?

Which has a higher resistance: a piece of copper wire or a piece of nichrome wire of the same length?

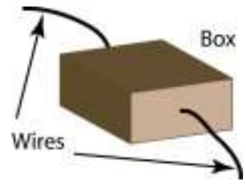
Homework Questions

1. Will the bulb light in the circuits shown below? Explain your answer briefly.





2. The box shown at right contains a material which is connected to the two wires. Describe an experiment which allows you to tell whether the material is a conductor or an insulator. Draw a diagram, and state how you would decide.



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3. In the set-up to the right, the bulb does not light.

Is there an insulator or conductor between the two wires? Name the insulator or conductor.

____

____

____

4. In your own words, describe why you think electrical wires are insulated.

____

____

____

____

Experiment: Ammeters and voltmeters

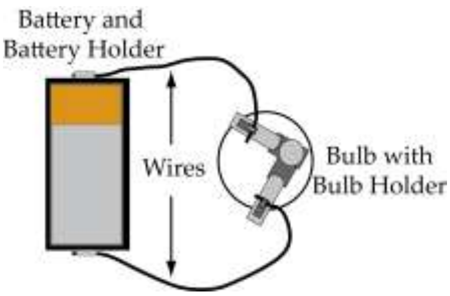
In this experiment, you may assume that:

- **Inside** a battery, the direction of current is from the negative terminal to the positive terminal ("from minus to plus")
- **Outside** a battery, the direction of current is from the positive terminal to the negative terminal ("from plus to minus")
- The brighter a bulb, the greater the current through it.

Section 1: Ammeters

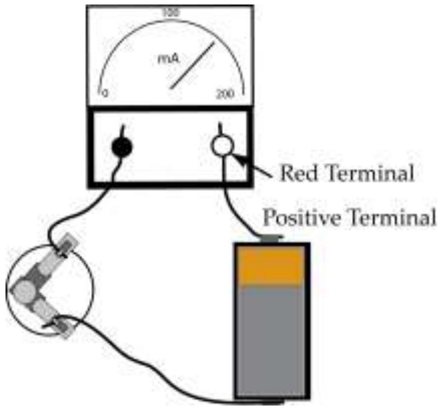
To measure current we use ammeters.

1. Draw a circuit diagram for the circuit shown.



Set up the circuit. Try and remember how bright the bulb is.

2. Now add an ammeter to the circuit as shown.



Does the ammeter change the current in the circuit? Explain how you can tell.

____

____

Is the ammeter a good conductor? Explain.

____

____

Does the ammeter have a low or a high resistance? Explain.

____

_

3. Suppose you switch the ammeter and the bulb. Do you think the ammeter reading would change? Explain.

___

___

__

Check your prediction. Does the bulb use up current?

___

_

4. Replace the bulb with a resistor. Write down the ammeter reading.

___

_

Is the current through a battery constant, or can it change? How can you tell?

___

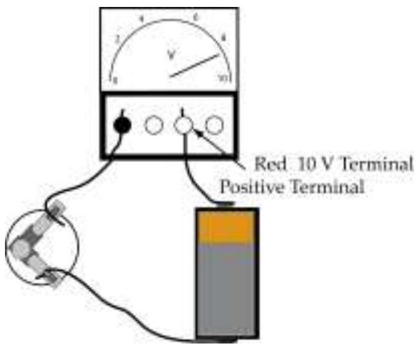
___

__

Section 2: Voltmeters

1. Set up the circuit at right.

Is the voltmeter connected in series or inparallel?



___

Does the bulb light?

___

Does the voltmeter change the current in the circuit? Explain how you can tell.

___

Does the voltmeter have a high or a low resistance? Explain.

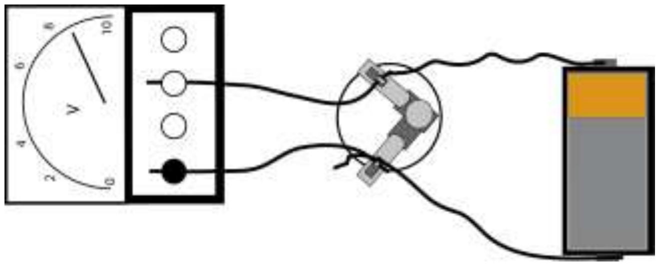
___

_

2. Draw a circuit diagram for the circuit below. How is the voltmeter connected now?

____

_



Set up the circuit. Does the bulb light?

____

_

Write down the voltmeter reading.

____

_

Does the voltmeter now have a noticeable effect on the current through the bulb? Explain.

____

_

In which set-up does the voltmeter appear to be more useful?

____

____

____

______

3. Replace the bulb with a resistor. Write down the voltmeter reading.

____

_

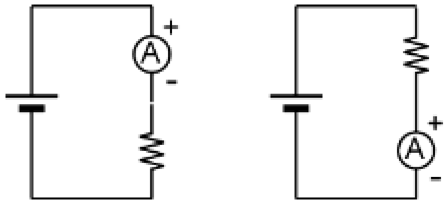
Does the voltage across a battery seem to be constant, or can it change?

____

_

Homework Question

1. Draw two experimental set-ups that correspond to the two circuit diagrams below. The two resistors are the same.



A student says that the ammeter readings are different, because in one of the circuits the resistor will have used up some of the current before it gets to the ammeter. Do you agree? Explain your answer.

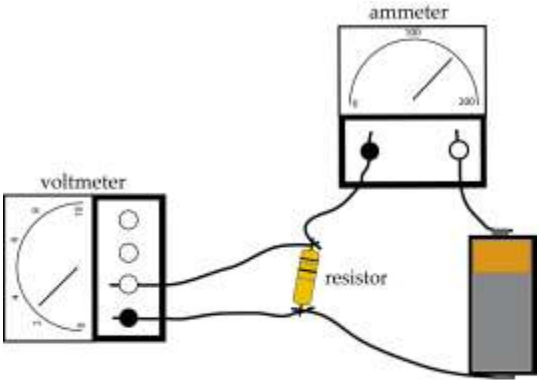
____

____

__

Mandatory Experiment: Ohm's Law

1. Set up the circuit shown. Measure the current and the voltage, and write your measurements in the first row of table 1.

   Some of the circuit elements get all the current. Name them.

   ____

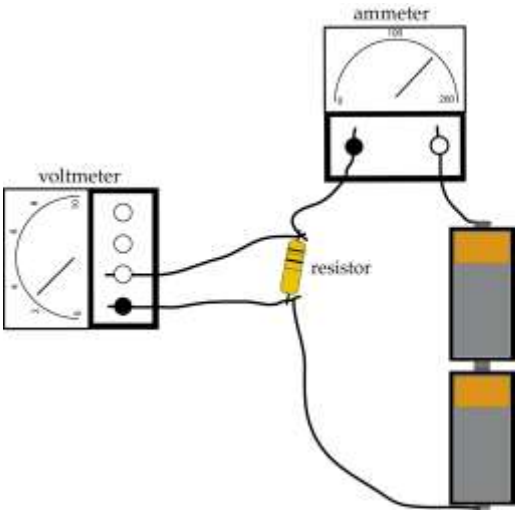
   ____

   Most, but not all of the current goes through the resistor. Explain why this is so.

   ____

   _

2. Add a second battery in series with the first as shown. Write down the new voltmeter and ammeter readings in table 1.

   When a second battery is added in series, what happens to the voltage across the resistor?

   ____

   ____

   ____

   When a second battery is added in series, what happens to the current through the resistor?

   ____

   ____

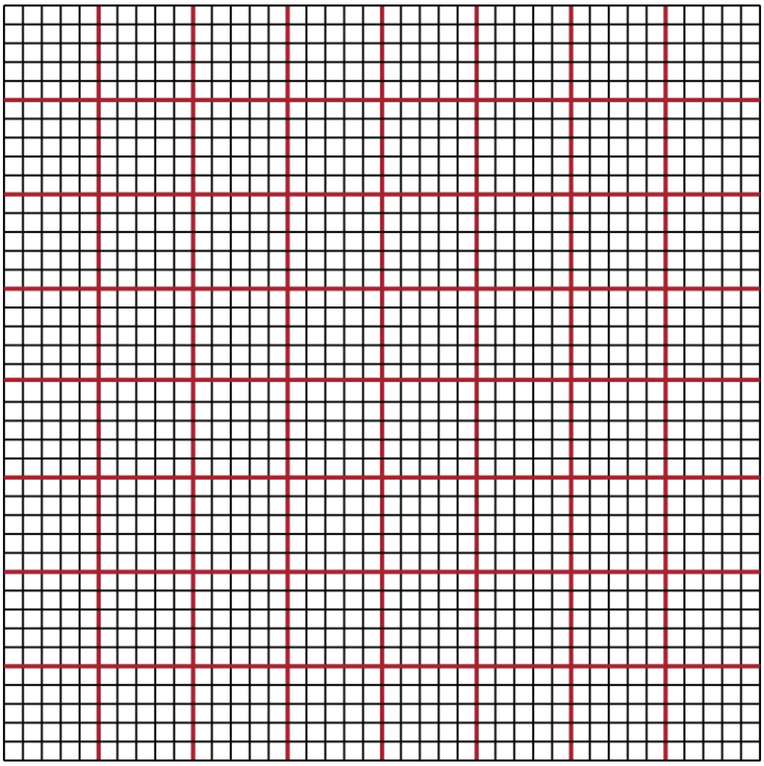
Table 1: Voltage and current for a resistor.

Number of batteries	Voltage (V)	Current (mA)	Current (A)
1			
2			
3			

3. Predict what would happen to the voltage and the current through the resistor when you add a third battery.

Check your predictions, and write your results in table 1.

4. If you have not done so already, convert your mA readings to A. Plot a graph that shows how the current through the resistor changes when the voltage across the resistor is changed. Plot voltage on the vertical axis, and current (in A) on the horizontal axis.



Do your data points appear to lie on a straight line?

Does the line appear to go through, or nearly go through, the origin?

What do these answers suggest about how voltage and current are related?

5. Find the value of the slope. What units do you use?

____

If you want to increase the current through the resistor by 1 A, by how much would you need to change the voltage? Explain.

____

____

6. The ratio of voltage and current is called the **resistance** of the resistor. Do you think the resistance of a resistor is constant? Explain how you can tell from the graph.

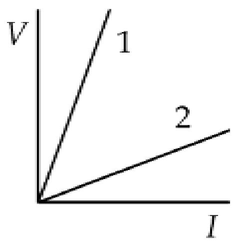
____

____

____

The relationship between voltage and current that you have found in this experiment is called **Ohm's Law**.

Homework Questions



1. A student carries out an experiment like yours for two different resistors, 1 and 2. She plots her results in a single graph.

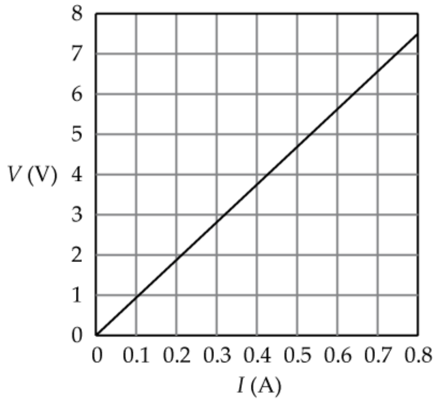
   Which resistor has the greatest resistance, 1 or 2? Explain.

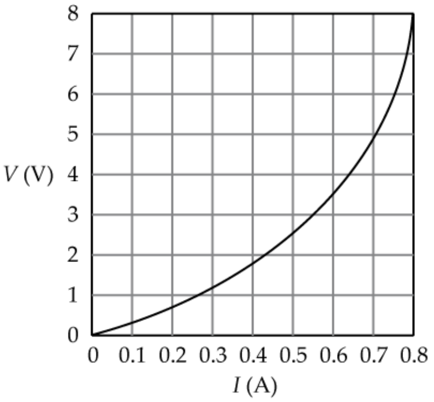
____

____

____

2. The graph on the left below shows how the current through a resistor changes when the voltage across it is changed. The graph at right below shows the same for a light bulb.





Use the graphs to calculate the resistance of the resistor when the current through it is 300 mA, and when it is 600 mA. Do the same for the bulb. Write your results in the table below.

	I (A)	*V* (V)	*R* (W)
resistor			
resistor			
bulb			
bulb			

In your own words, explain how you can tell, just by looking at the shape of the graph, how the resistance of an object changes when you increase the current through that object.

Does Ohm's Law apply to a light bulb? Explain how you can tell.

Appendix B Interview Protocol for Cycle 1

Protocol for Focus Group Interviews [28.11.12]

Science Teaching and Inquiry:

School Placements:
What was your teaching placement school like?
What was the science teaching like? Would you say it was good teaching? Why or Why not?
Was it like you experienced when you were in secondary school?
Did you observe any inquiry in the lessons you saw while observing during teaching placement?
Do you think other teachers, that you did not observe, were doing inquiry?

How comfortable/confident did you feel teaching science in your school placement?
Did you feel ready to teach by inquiry?
Did you feel you got a chance to use inquiry activities during teaching placement? Why or why not? If you did, can you describe it in more detail?
How did you develop the lesson plan?
Did it seems like the students were capable to do inquiry?
How do you think it went? Were you encouraged and interested in trying more, or put off?
Have your notions of inquiry changed as a result of your teaching placements? How?

This Friday you will go back to planning inquiry lessons as part of lab.
How are you thinking about including inquiry in those lessons?
Did your teaching placement change how you are thinking about designing the lessons for your scheme of work for the module?

Protocol for Focus Group Interviews [31.10.12]

Warm up Question:
Before we get into the interview itself, we wanted to ask you a couple questions about the module and how you do the work from the labs.

Can you talk about how you prepare the lab reports for the Wednesday Physics lab?
How do you divide the work?
Where and when do you work on the reports?
Has your current system of dividing the work been successful for your group?

Science Teaching and Inquiry:
Prior Science Learning
How were you taught science in secondary school?
Can you describe what a typical day would be like?
Did you feel (at the time) it was a good way to learn science?
Looking back at that teaching now how do you feel about learning and teaching science that way?

Inquiry
You have been at DCU and now have science learning experiences here, as well as modules about how to teach science in secondary school.
What have you been taught science here at DCU?
How is it different or similar to the way you learned science in secondary school?

In your modules at DCU there has been talk about inquiry science teaching.
What is inquiry?
How would you describe it to someone that is not in your module(s)?
What are the key features?
How do you "know it when you see it"?
Can you talk about your sense of the difference between open, guided and traditional teaching? Are there labs from this semester or previous semesters at DCU that you would put in these categories?
After completing an inquiry exercise such as the ones you have carried out, do you think students have learned enough about the topic? (Forces for example..)
Would you use exercises such as the homework questions as a way of testing the students?
Have the labs or the microteaching changed the way you think about good science teaching?

School Placements:

Do you feel ready to teach science in your upcoming school placement?
Do you feel ready to teach by inquiry?
Is there is a difference in your feeling of preparation between these two?
How do you imagine you will teach science in your school placements?
Will that be different from how you imagine you will teach science when you are in your own science classroom someday?

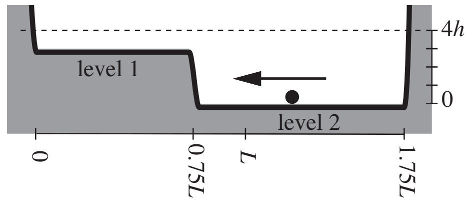
Appendix C Classical Probability Tutorial

CLASSICAL PROBABILITY

Name ____________________

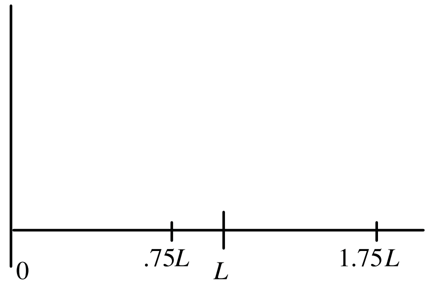
Balls on tracks

A ball rolls back and forth in a track with very steep sides. Two levels of unequal length joined by a steep ramp form the base of the track. A large number of photographs of the system are taken at random times. You may assume that the time spent on the steep portions is negligible. Assume there is no friction or energy loss in the system, and that the ball rolls smoothly, without bouncing, forever. Level 1 has a length of 3/4L, and level 2 has a length of L. Assume the ball was dropped from a height of 4h.



A. *Probability*

1. Sketch the gravitational potential energy corresponding to this situation between $x = 0$ and $x = 1.75L$.



2. Is the speed of the ball on level 1 *greater than, less than,* or *equal to* its speed on level 2? Explain.

   For the ball, is the amount of time that it spends on level 1 *greater than, less than,* or *equal to* the amount of time it spends on level 2? Explain.

3. Suppose a single photograph were taken at a random time. On the basis of your results above, is the probability of the photograph showing the ball on level 1 *greater than, less than,* or *equal to* that of the photograph showing the ball on level 2? Explain.

4. Determine the probability of finding the ball on each level. Explain.

✓ Check your results with a tutorial instructor.

B. *Probability density*

Imagine splitting level 2 into two unequal segments: segment "2A" from x = .75L to $x = L$, and segment "2B" from $x = L$ to $x = 1.75L$.

1. Find the probability that out of anywhere in the system the ball is found:

   a. along segment 2A

   b. along segment 2B

   Explain your reasoning.

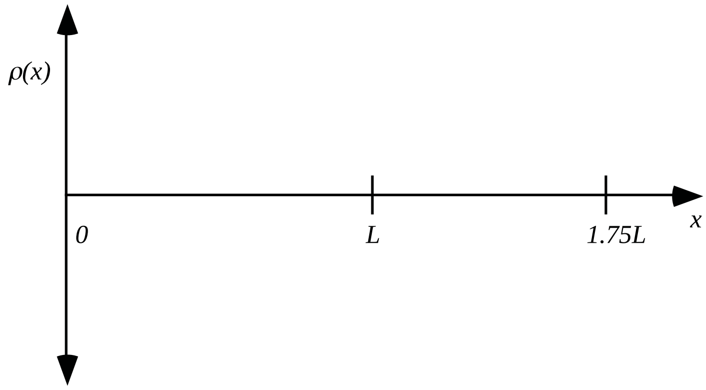
Consider the following ratio for each segment: The probability of finding the ball along that segment divided by the length of that segment.

2. Is the above ratio larger for segment 2A, larger for segment 2B, or is it the same for both segments? Explain.

The ratio defined above is called *probability density*.

3. Compare and contrast *probability density* with other densities that you have encountered in physics. What are the units of probability density in this case?

4. In the space at right, carefully draw a graph of *probability density, ρ(x),* versus *position* from $x = 0$ to $x = 1.75L$. Label relevant values on the vertical axis.



5. What feature of the graph represents the probability of finding the ball in an arbitrarily chosen interval between $x = x_1$ and $x = x_2$?

6. What is the probability of finding the ball *exactly* at $x = L$? Explain.

7. What answer would you expect for the probability of finding the ball anywhere between $x = 0$ and $x = 1.75L$? Show that your graph of probability density gives you the answer you expect.

8. Suppose you were given an arbitrary probability density function *ρ(x) (i.e., one that does not have a shape as simple as the one above).* Write a mathematical expression for the probability of finding the ball between $x = x_1$ and $x = x_2$.

Appendix D Reflection Sheet for Video Workshop

How did your initial ideas for the classes compare with how you would plan this topic now?

- Did you learn anything new about inquiry?

- Did you learn anything new generally (about pressure, other aspects of physics)?

- How did your understanding of pressure compare to the students' understanding of pressure?

- Did your understanding of pressure change/develop throughout?

- Would you like to try and teach in that style?

Would you feel confident to teach a class in that style?

Difficulties you think you would find teaching in this way.

- Do you think the videos represented good inquiry lessons?

- Overall likes/dislikes about how the class was taught.

Appendix E Informed Consent Form

DUBLIN CITY UNIVERSITY
Informed Consent Form

Research Study Title: ***Investigating the development of pre-service teachers' understanding of inquiry science teaching***

During module PS255, you will use and critique classroom resources developed for teacher education programmes in Inquiry Based Science Education. To determine the effect of the module we ask you to contribute to the evaluation of this module through allowing us to quote anonymously from assessments, and/or involve you in interviews, and/or ask you to complete questionnaires on a voluntary basis. Interviews may be recorded to ensure accuracy of transcription. In a few cases, assessment sheets from school placement supervisions maybe used to ascertain if and to what extent inquiry is used in the classroom.

During module ES216, you will be introduced to a variety of teaching and learning approaches which are designed to prepare you for your School Placement. As part of this module you will code and analyse videos of teaching episodes before and after your placement. You will also partake in group discussions relating to your analysis of these episodes. In order to determine the effect of the module we ask you to contribute to the evaluation of this module ask you to complete questionnaires on a voluntary basis and allow video recording of the group discussions relating to your video analysis.

All raw data collected from the participants will be coded to ensure confidentiality and protected according to national (Data Protection acts 1998 & 2003) and international legislation (EU Directive 95/46/EC). All students who have participated in the project will receive access to the reports produced.

You may choose to consent to participate in only some aspects of the study, and you may withdraw from any aspect of the Research Study at any point. Your involvement or non-involvement in any element of the project will not affect your ongoing assessment/grades/management. A study of your school placement assessment will in no way affect the grade you will receive. We will simply observe where, if at all, teaching by inquiry takes place. As always, it is possible to get an outstanding mark for a class that involves no inquiry at all.

<u>Participant – please complete the following (Circle Yes or No for each question)</u>

I have read the Plain Language Statement (or had it read to me)	*Yes/No*
I understand the information provided	*Yes/No*
I have had an opportunity to ask questions and discuss this study	*Yes/No*
I have received satisfactory answers to all my questions	*Yes/No*
I am aware that my interview will be audiotaped	*Yes/No*
I am aware that group discussions will be video recorded	*Yes/No*

However, only anonymized transcripts will be used.

<u>Signature:</u>

I have read and understood the information in this form. My questions and concerns have been answered by the researchers, and I have a copy of this consent form. Therefore, I consent to take part in this research project

Participant's Signature: ______________________________

Name in Block Capitals: ______________________________

Witness: ______________________________

Date: ______________________________

PLAIN LANGUAGE STATEMENT

This project researches the attitudes of pre-service teachers towards inquiry-based science education and their ability to critique and analyse video recorded teaching episodes in terms of general and specific teaching methodologies. The project will be led by Prof. Scott McDonald, Dr. Paul van Kampen and Dr. James Lovatt, supported by Mr. Paul Grimes and Ms. Leanne Doughty.

The aim of the project is to investigate the way that teacher candidates develop their understandings around inquiry science teaching practices and general teaching strategies and methodologies including assessment, classroom management, differentiating learning and effective planning.

Inquiry science teaching is a difficult and ambitious form of science teaching, and there are challenges for any teacher in developing these practices. To be able to support teacher candidates in an initial teacher training program to engage in these practices is a challenge for teacher educators. In order to improve the quality of the modules that are delivered and to help the field of science education better understand the challenges and processes of learning to teaching with inquiry, this study will investigate the trajectories of groups of pre-service teachers across two modules, PS255 and ES216. PS255 involves two elements, an inquiry science based laboratory and ICT lectures designed to support inquiry science teaching. ES216 is a micro teaching course structured with a similar focus to support students' development of teaching methodologies and strategies including inquiry based learning.

Through completion of questionnaires, video recorded discussion of analysed teaching episodes, examination of teacher candidate assessment artefacts, interviews, and examination of documents from their field supervisors, we hope to better understand what aspects of the practice they most struggle with, what teacher education practices best support their development, and how their growth over the semester can be characterised. Special attention will be given to the assessment of module PS255, which will consist of providing ungraded feedback that gives groups the chance to change their initial report, and then grading the end product.

The assessment of module PS255 will also feed into the SAILS project. SAILS is an European FP7 Science in Society funded project coordinated by DCU's Centre for the Advancement of Science and Mathematics Teaching and Learning (CASTeL), led by the Principal Investigators: Dr. Eilish McLoughlin (Eilish.McLoughlin@dcu.ie), Dr. Odilla Finlayson (Odilla.Finlayson@dcu.ie) and Dr. Paul van Kampen (Paul.van.Kampen@dcu.ie), supported by Dr. Sarah Brady and Dr. Deirdre McCabe.

The aim of SAILS is to support teachers in both adapting Inquiry Based Science Education (IBSE) at second level (students aged 12 to 18 years) across Europe, which will be achieved by utilising existing models and resources for both pre-service and in-service teacher education in IBSE, and to prepare science teachers to be confident and competent in the assessment of their students' learning through inquiry.

Appendix F Transcript of Discourse from Cycle 3

1	*Jim*	*Let's actually find out why that happened then.*	*prompt*	*oos*
2	*Barbara*	*the pressure in the tank*	*claim*	*oos*
3	*Jim*	*is less than the pressure outside. [pause]*	*claim*	*sos*
4	*Jim*	*That only happened because the valves were left open.*	*claim + warrant*	*sos*
5	*Denise*	*Closed*	*rebuttal*	*oor*
6	*Barbara*	*Closed [pause]*	*rebuttal*	*oor*
7	*Barbara*	*So the valves were closed*	*data*	*oos*
8	*Jim*	*So if they had been left open there would have been…*	*claim*	*oos*
9	*Denise*	*… there would have been air (0:02:23)*	*claim*	*oor*
10		*[pause]*		
11	*Jim*	*Do we… define what pressure was?*	*prompt*	*ooq*
12	*Barbara*	*Huh?*	*clarification*	*oor*
13	*Jim*	*Do we have to define what pressure is? If we're teaching this?*	*prompt*	*ooq*
14	*Barbara*	*Yes. Pressure is force divided by area.*	*data*	*oor*
15	*Cheryl*	*I think we have to find out why that is, why that happened.*	*prompt*	*oor*
16	*Jim*	*But we have that in one line – pressure [pause]*	*rebuttal*	*oor*
17	*Jim*	*So what's pressure? [pause]*	*prompt*	*soq*
18	*Jim*	*What is the standard atmospheric pressure? [pause]*	*prompt*	*soq*
19	*Barbara*	*Do you know when you heat a coke can and you put it in water and then it collapses... is that the same... just on a bigger scale? (0:04:09)*	*data + claim*	*soq*
20				
21	*Barbara*	*Yeah so it's the same thing… the heat inside… and then when it hit normal pressure…*	*claim*	*sor*
22		*Some clarification about the task*		
23		*[...]*		
24	*Barbara*	*They steam cleaned it… they steam cleaned it inside, they closed it, the steam stayed...*	*data*	*sos*
25	*Jim*	*… and then when they opened…*	*prompt*	*oor*
26	*Barbara*	*… and when they opened it, it hit normal air… and collapsed.*	*data*	*sos*
27	*Denise*	*But I don't think they did open it*	*rebuttal*	*oor*

28	*Jim*	*They said it was left closed*	*warrant*	*oor*
29	*Barbara*	*But is that when they opened it?*	*clarification*	*soq*
30	*Jim*	*That's why I was getting confused, that's why I said opened it. It shouldn't change if it was closed.*	*claim*	*sos*
31	*Denise*	*Read the description [non-confrontational]*	*prompt*	*oor*
32	*Cheryl*	*Or, the air built up so much that it actually forced the thing open and it collapsed (0:05:38)*	*rebuttal*	*oor*
33				
34	*Barbara*	*So really they just created a [nothing]*	*prompt*	*sos*
35		*[Gap of silence ~40 sec]*		
36	*Jim*	*So are we saying what happened was they put a vacuum on the tank and explain how that vacuum...?*	*claim*	*ooq*
37	*Denise*	*It says though the valves were disabled and removed, does that mean they are not there? (0:06:58)*	*rebuttal + claim*	*oor*
38		*[long gap]*		
39	*Barbara*	*Heated air has more pressure than unheated air so there is more pressure inside the tank*	*warrant + claim (not data)*	*sos*
40	*Jim*	*than the outside.*	*clarification*	*oos*
41	*Barbara*	*Than the outside [pause]*	*(with before)*	
42	*Barbara*	*It has to… it has to beat the pressure outside, where, because it's the pressure outside that makes it implode.*	*warrant + claim*	*sos*
43	*Jim*	*Is it kind of like what we did yesterday with the marshmallow things? Where we opened up the thing and... but it's the opposite way around*	*claim + data*	*oos*
44	*Denise*	*Did you do the coke can experiment at school? Heat up the can then put it in the water and then it collapses because the water force on it because there is no air inside it anymore*	*data + claim*	*oos*
45	*Instructor*	*So what have we got so far?*	*prompt*	
46		*All: Not a lot*	*data*	
47	*Instructor*	*You've definitely talked about something. So you have [on*	*prompt*	

		poster] pressure on the outside is greater than the pressure on the inside. Ok. Even before all that.		
48	*Denise*	*Are the valves open?*	*clarification*	*oos*
49	*Instructor*	*They're closed*		
50	*Jim*	*And then do they open? To cause the thing to…?*		
51	*Instructor*	*Well it was cleaned, so obviously there had to be something open to get the steam cleaning inside and then when they were done they shut everything and left it and that happened at some stage.*		
52	*Jim*	*We thought it was different*		
53	*Instructor*	*So… ok if we think of even a... So before they start cleaning it, what's going on? What does it look like? What is inside? (0:09:11)*	*prompt*	
54	*Jim*	*It's just standard like tank or something*	*data*	
55	*Instructor*	*So is it empty?*	*prompt*	
56	*Barbara*	*Air inside*	*claim*	
57	*Jim*	*Yeah empty, with just normal air*	*qualifier*	
58	*Instructor*	*So does air mean it's empty then?*	*claim*	
59	*Barbara*	*No*	*rebuttal*	
60	*Denise*	*No*	*rebuttal*	
61	*Instructor*	*So is there any way that might help you along? Is there any way you can represent that? [pause]*	*prompt*	
62	*Instructor*	*So here there is air all around us, but… if we were to look closer, like a lot closer, what would we see?*	*prompt*	
63	*Cheryl*	*The different gases, like oxygen*	*data*	
64	*Instructor*	*And what is a gas, what is it made up of?*	*prompt*	
65	*Denise*	*A vapour?*	*claim*	
66	*Instructor*	*Ehm… not sure about vapour… so it's not nothing, it's made up of things. … If you were to draw a gas how would you draw it?*	*prompt*	
67	*Denise*	*A few molecules or something?*	*claim*	
68	*Instructor*	*Ok yeah, so that might be a good place to start with this. …*	*prompt*	

		If you're able to draw that it might lead you to the next step (0:11:50)		
69		*[pause] they make some inaudible comments while drawing things*		
70	*Barbara*	*If you draw the diagram of the tanker…*	*prompt*	*oos*
71	*Denise*	*Can anyone draw…?*	*prompt*	*ooq*
72	*Cheryl*	*Not really*	*prompt*	*oor*
73	*Barbara*	*Well it's just a cylinder with a thermometer*	*claim*	*oos*
74	*Jim*	*Did he say draw as if the…?*	*clarification*	*ooq*
75	*Denise*	*So like there is… I don't even know what a molecule is supposed to look like*	*claim*	*oos*
76	*Jim*	*Just draw little circles or something [pause]*	*claim*	*oos*
77	*Jim*	*And when they put the vacuum in, the molecules all move closer together? [pause]**this is a statement, not a response type question***	*data+claim*	*oos*
78	*Denise*	*Ehm… [pause]*	*prompt*	*oos*
79	*Denise*	*So they all move closer?*	*claim*	*sos*
80	*Barbara*	*Yeah, like they compress... [pause]*	*warrant*	*oos*
81	*Barbara*	*Oh, no...*	*rebuttal*	*oor*
82	*Denise*	*Yeah, because you're putting something else into it, which would make them go*	*warrant*	*sos*
83	*Jim*	*oxygen or [inaudible]*	*data*	*oos*
84	*Barbara*	*So heat goes in but the pressure... the pressure… yeah, there is more pressure, so they have to… yeah…*	*data+claim*	*sos*
85	*Jim*	*[inaudible] experiment with vacuum [pause]*	*data*	*oos*
86	*Jim*	*Like would the growing and shrinking of the marshmallows be the same as what happened?*	*claim*	*ooq*
87	*Barbara*	*Yeah… [inaudible]*	*prompt*	*oor*
88	*Jim*	*Maybe?*	*prompt*	*ooq*
89	*Cheryl*	*Yeah?*	*prompt*	*oor*
90	*Jim*	*Because they are getting smaller or getting bigger [inaudible]*	*warrant*	*sor*
91	*Barbara*	*Well it must expand and then suddenly just... the air inside...*	*claim*	*oor*
92	*Jim*	*It's like you know if you throw like tin or something onto a fire*	*data*	*oos*

93	*Barbara*	*Yeah*	*prompt*	*oor*
94	*Jim*	*It shrinks so it's quite similar to that*	*claim*	*sor*
95		*Group members agree*		
96		*No talking about problem until ~ 0:15:30*		
97				
98	*Denise*	*So surely it moved closer because if you are using a steam cleaner you are adding more molecules into it.*	*claim + warrant*	*oos + oos*
99	*Barbara*	*Well in the general picture we know that the… we know there is more pressure because we are adding in heat*	*claim + warrant*	*oos + oos*
100	*Jim*	*The change in temperature is causing it to get smaller isn't it? (0:16:37)*	*claim*	*ooq*
101				
102	*Jim*	*So when they add the volume...when they put in the vacuum it loses all its atmospheric pressure yeah?*	*claim*	*ooq*
103	*Barbara*	*Yeah the pressure increased*	*claim*	*oor*
104	*Jim*	*The pressure increased?*	*prompt*	*ooq*
105	*Barbara*	*I'm not certain*	*prompt*	*oos*
106	*Jim*	*It is actually, yeah*	*claim*	*sos*
107	*Denise*	*Yeah because if it is*	*(ignore)*	
108	*Instructor*	*[Questions about what is drawn so far]*		
109	*Instructor*	*What are these molecules doing?*	*Prompt*	
110	*Denise*	*They're just moving around*	*Claim*	
111	*Instructor*	*And is it just those?*	*Prompt*	
112	*Denise*	*There could be others*		
113	*Instructor*	*And in the area that the tank is in?*	*Prompt*	
114	*Denise*	*Like the ones outside?*	*Claim*	*sos*
115	*Jim*	*So they're going to be the exact same yeah?*	*Claim*	*oos*
116	*Instructor*	*And what are the ones outside doing?*	*Prompt*	
117	*Jim*	*They're interacting with the tank and pushing in on it*	*Claim*	
118		*Group start to draw arrows*		
119	*Instructor*	*So are you happy you have a picture of something that you can use to explain what the situation was like before cleaning started? (0:19:27)*	*prompt*	
120				

121	*Instructor*	*So then if you think about what's happening inside the tank and how that might affect what's going on?*	*prompt*	
122	*Jim*	*So it's getting pulled together maybe?*	*claim*	*oos*
123	*Barbara*	*The molecules are compressing inside? (tentatively)*	*claim*	*oos*
124	*Denise*	*Because the pressure is greater*	*claim*	*oos*
125	*Instructor*	*Ok so how would that tell you that… closer together?*	*prompt*	
126	*Barbara*	*Well like if it's heated does the pressure like…*	*claim (start of a claim)*	*oor*
127	*Denise*	*The atoms will get excited with the heat from the…*	*warrant (relating to above claim)*	*oos*
128	*Instructor*	*(And what will happen if they get excited?)*	*prompt*	
129	*Jim*	*Expand (all in agreement)*	*claim*	
130	*Instructor*	*They're going to move, yeah. … Is it going to change compared to the way they move normally?*	*claim followed by clarification(self oriented)*	*soq*
131	*Jim*	*More*	*prompt*	*oos*
132	*Instructor*	*So what do we do when we heat something?*	*prompt*	
133	*Denise*	*It expands*		
134	*Instructor*	*Yeah, so it expands, but how do we know… when we talk about molecules … can we say something about how fast they are going?*	*prompt*	
135	*Denise*	*They get excited, they move a lot quicker.*	*claim*	
136	*Instructor*	*Yeah*		
137	*Denise*	*The experiment we did in chemistry*	*data*	
138		*Some general talk for ~ 1 min (0:21:08)*		
139		*Some talk about not being used to this*		
140	*Denise*	*So they're expanding is it, and they're moving around faster?*	*clarification+claim*	*ooq + ooq*
141	*Barbara*	*Yeah*	*claim*	*oos*
142	*Barbara*			
143		*[pause]*		
144	*Denise*	*Are we saying it's because of the steam cleaner thing, that the molecules are becoming… excited?*	*clarification+claim*	*ooq + ooq*
145	*Cheryl*	*Yeah*	*claim*	*oos*
146	*Barbara*	*Yeah*	*claim*	*oos*

147	*Denise*	*So molecules on the inside become excited and expand and move around more, due to… the heat*	*claim+warrant*	*oos + oos*
148		*[pause]*		
149	*Cheryl*	*If they clean for the whole night, how did they stop the steam?*	*rebuttal*	*ooq*
150	*Barbara*	*I think they just cleaned and then closed it? Like the steam just stays in.*	*claim+warrant*	*oos + oos*
151	*Cheryl*	*Ok. [pause]*		
152	*Denise*	*But at some point does it not have to like all come back again so the pressure on the outside is standard to make it compress? (0:25:03)*	*rebuttal*	*ooq*
153	*Barbara*	*Say that again?*	*clarification*	*oos*
154	*Denise*	*Do you know the way we are saying that they all move around but like would the pressure on the inside not have to like really decrease then because this has to push in on it?*	*data + claim*	*oos + ooq*
155	*Barbara*	*It must at some stage like, it's not going to stay. Like there has to be some...*	*claim+warrant*	*oor + oos*
156	*Denise*	*Ok, so then... [pause]*	*prompt*	*oos*
157	*Denise*	*So, we could say… [inaudible]*	*prompt*	*oos*
158	*Barbara*	*Ehm so... it's hot when it moves in, right, so molecules get excited, they're moving around, higher volume, higher energy, higher temperature... What's the relationship between temperature and pressure?*	*split into 2: data + claim + warrant, and prompt*	*sos+sos+sos; ooq*
159	*Denise*	*The higher the temperature…*	*prompt*	*oos*
160	*Barbara*	*… the lower the pressure…*	*claim*	*oos*
161	*Denise*	*… the lower the pressure inside I think, yeah...*	*claim*	*oor*
162	*Cheryl*	*yeah…*	*prompt*	*oor*
163	*Denise*	*... because...*	*prompt*	*sos*
164	*Barbara*	*yeah…*	*prompt*	*oor*
165	*Denise*	*... you are pushing...*	*warrant*	*sor*
166	*Barbara*	*yeah…*	*prompt*	*oor*
167	*Denise*	*… or is it pressure is getting higher because you are pushing everything... [pause]*	*rebuttal*	*soq*
168	*Barbara*	*We'll just look it up [pause]*	*prompt*	*oor*
169	*Cheryl*	*Boyle's law... Charles' law*	*data*	*oos*

170		*(0:27:49)*		
171	Barbara	*Oh so it's a function of*	claim	oor
172	Cheryl	*So as temp increases...*	claim	sos
173	Barbara	*... pressure increases*	claim	oor
174	Jim	*What happens here again? The ehm… [pause]*	prompt	ooq
175	Jim	*Because you're increasing…*	claim	sor
176	Denise	*So we're trying to say now is… which one is that?*	clarification	oor
177	Jim	*This one here*	clarification	oor
178	Denise	*As temperature increases, pressure increases… it's just a reminder, more than anything… … If it's starting to cool down or something they are starting to move closer together… […] the pressure and then the pressure inside is increased because…*	claim + warrant + claim	oor + sos + sos
179	Barbara	*Yeah… Because obviously the temperature is going to have to... the temperature has to go back down, so that means pressure goes down*	claim + warrant	oos + sos
180	Jim	*In the equation you have there is wrong I just googled it there. Do you know that one Boyle's Law*	rebuttal	oos
181	Cheryl	*Boyle's Law and Charles' Law*	data	oor
182	Barbara	*And Gay-Lussac's law*	data	oor
183		*(0:30:12)*		
184	Jim	*And who? I never heard of him. [interactions] Will we write down the equation then we can plot the different things and then just say how the equation works?*	prompt	ooq
185	Cheryl	*And why it works*	prompt	oor
186	Denise	*What equations?*	clarification	oor
187	Jim	*Can you see that, p_1V_1 over temperature, so… [unclear]*	data	oos
188	Denise	*When you are explaining that to kids, they won't understand those... they're more Leaving Cert.*	claim	oor
189	Barbara	*So we know that temperature and pressure are proportional*	data	oos
190	Cheryl	*And I'd… I'd say the volume as well*	claim	oos

191	*Barbara*	*Yeah*	*claim*	*oor*
192	*Cheryl*	*Because the volume does change when those two things are changed*	*warrant*	*sos*
193	*Barbara*	*Yeah*	*prompt*	*oor*
194	*Denise*	*Yeah*	*prompt*	*oor*
195	*Barbara*	*They're proportional, so as temperature increases the pressure increases. And volume…*	*claim + warrant*	*sos + sos*
196	*Denise*	*And somehow the pressure is going to have to go down…*	*claim*	*oor*
197	*Jim*	*And volume decreases though*	*claim*	*oor*
198	*Barbara*	*Is that not good/given/*	*Clarification*	*ooq*
199	*Barbara*	*So then the temperature will drop… like it's not going to stay… [unrelated]*	*claim*	*sor*
200	*Barbara*	*So then the temperature at some stage is going to drop, it's not going to stay at a constant temperature so then when the temperature drops the pressure will drop, and then the pressure outside it is still compressing it on the outside so when the lower pressure inside…*	*claim+claim*	*sos+sos*
201	*Denise*	*And it will compress more on the outside, I think to make it come in…*	*warrant*	*oor*
202	*Barbara*	*I think, like…*	*prompt*	*oor*
203	*Jim*	*Three things we have is pressure, volume and temperature, so two of them are increasing and one of them is decreasing, yeah?*	*data + clarification*	*ooq +oos*
204	*Denise*	*Yeah, I think so*	*claim*	*oor*
205	*Jim*	*We're getting somewhere*	*prompt*	*oos*
206	*Denise*	*But if the pressure is increasing would the volume not increase as well because…*	*rebuttal*	*ooq*
207	*Jim*	*So the pressure increasing?*	*clarification*	*ooq*
208	*Denise*	*… it expands? (0:33:29) [pause]*	*clarification*	*soq*
209	*Instructor*	*So how are we going now?*		
210	*Denise*	*We're just trying to figure out now, like, the temperature will have to decrease at some point, and with that would the pressure decrease as well which makes these ones on the*		

		outside pushing in more		
211	*Jim*	*Wait if we haven't…*		
212	*Instructor*	*Ok. Ehm… Ok so what have we here?*		
213	*Denise*	*It's just a reminder. kind of*		
214	*Instructor*	*Yeah, so you're certainly right in saying the temperature is going to… because it's overnight, things are going to cool down. So what does that mean, when things cool down?*		
215	*Denise*	*These will slow down with their movement and then kind of move in closer together*		
216	*Instructor*	*[…] What do these do when they move around?*		
217	*Denise*	*They bounce off each other and bounce off the side and stuff*		
218	*Instructor*	*So what does that mean when they bounce?*		
219	*Denise*	*They're creating like an energy…*		
220	*Instructor*	*Yeah, yeah*		
221	*Denise*	*kinetic energy… because they're moving…*		
222	*Instructor*	*Yeah. We have this term here so as temperature increases… what does pressure mean?*		
223	*Denise*	*The force inside the container*		
224	*Instructor*	*[…] And how would you explain force in everyday terms?*		
225	*Denise*	*Like the strength of the air inside*		
226	*Jim*	*Yeah, something exerted on another thing, […] pushing*		
227		*All agree that molecules are doing something, causing the pressure […]*		
228	*Denise*	*So we'll say that because it was left overnight the temperature decreases [pause]*	*data*	*oos*
229	*Denise*	*As the container was left overnight the temperature decreased along with the pressure*	*claim*	*sor*
230	*Jim*	*See, if we use this formula, then we can kind of work out if the pressure increases if the other two do. Temperature and pressure are proportional so if*	*claim+ warrant*	*oos + oor*

		temperature increases or if the pressure increases the temperature will increase too. (0:35:17)		
231	*Barbara*	*Yeah*	*prompt*	*oor*
232	*Jim*	*So therefore the volume is going to increase. What happens if…?*	*claim + prompt*	*sor + ooq*
233	*Denise*	*They are all proportional or are they not, because, if you…*	*clarification*	*ooq*
234	*Jim*	*So you think temperature is going to increase as well if pressure and volume increase?*	*clarification*	*ooq*
235	*Denise*	*Well temperature will increase anyway if the volume… the pressure increases*	*claim*	*oor*
236	*Jim*	*… So once one of them increases they all increase?*	*calrification*	*ooq*
237	*Denise*	*I think so.*	*prompt*	*oor*
238	*Jim*	*So that's why it gets smaller because*	*claim*	*oos*
239	*Denise*	*Because it's starting to decrease then.*	*data*	*oor*
240	*Jim*	*Is the temperature going to rise?*	*prompt*	*ooq*
241	*Denise*	*It is but then it is left overnight to cool… And it starts to decrease a little bit.*	*rebuttal + claim*	*oor + oos*
242	*Jim*	*How does to cool?*	*clarification*	*ooq*
243	*Denise*	*They turn the cleaner off. We were told because it's left overnight it will cool.*	*warrant*	*oos*