UNIVERSITY of LIMERICK
OLLSCOIL LUIMNEACH

TO DETERMINE AND OVERCOME MISCONCEPTIONS IN BIOLOGY HELD BY STUDENTS AND EDUCATORS IN THE IRISH SCHOOLING SYSTEM

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Abstract

To determine and overcome misconceptions in Biology held by students and educators in the Irish Schooling system

The investigation of misconceptions in Biology has been a substantive feature of the work of the Science Education research community for the past 30 years. It has been found to be one small but important aspect of teaching conceptual change in the classroom and is part of the broader educative work of the teacher and educator – generally regarded as work that is intellectual, social, moral and political. The importance of investigating misconceptions is emphasised by the number of pre-service teachers, qualified teachers and teacher educators that possess misconceptions and are unknowingly transferring these misconceptions to the students they teach. Misconceptions are a major concern in Science education as student’s capacity to acquire new and accurate scientific knowledge appears to depend greatly on pre-existing beliefs and the capacity to think anew and engage in deep meaning making, from factual information to higher-order conceptual thinking. Understanding the nature of conceptual change, and how to encourage and direct it, has been a major concern in Science education research. The area of conceptual change research is still a highly contested and disordered one. A handbook on conceptual change has the potential to help educators pitch the curriculum at the right level; design instruction to support teaching, and inform teachers how to bring about such conceptual changes. However, it is not intended as some type of magic bullet or a quick and lasting solution to a complex problem. The main literature in the conceptual framework looks at the complexity of learning, teaching and the importance of continual professional development as well as the challenges of school culture.

This study took place in the University of Limerick, it involved student teachers from their second and third year (n=154) of teacher education, experienced Biology teachers (n=45) and senior cycle students (n=1,315) from forty seven secondary schools in the Republic of Ireland. The purpose of this investigation was to identify the misconceptions in Biology that students, pre-service teachers and qualified teachers hold and to determine how individuals learn information and what influences or underpins their learning. The study then aimed to determine what contributes to the formation of these misconceptions and hence develop, implement and evaluate cited conceptual change strategies that might help to better recognise, reduce and ultimately remove the complex problem of misconceptions in the learning and understanding of the particular topics for students and teachers in Ireland. This is a complex and difficult area of science education, it is a work in progress, and the author tried to find useful conceptual tools and practices to create awareness of misconceptions and to scaffold and support the acquisition of accurate scientific disciplinary knowledge.

There were three distinct phases in this investigation. Phase one involved the development of a paper and pencil identification instrument to identify the misconceptions present among Irish senior cycle students, pre-service teachers and qualified teachers. The identification instrument consisted of a variety of questions on topics in Biology that were found to have misconceptions among participants in International studies. Findings from this phase indicate the presence of misconceptions amongst all three groups. However, the qualified teachers held fewer misconceptions and answered more questions correctly than the other two groups.

Phase two of this investigation involved the development of an additional pedagogy module for third year pre-service teachers in the University of Limerick. This module aimed at creating awareness of misconceptions; what they are, how they are developed, identified and tackled. This phase also involved the development of a website resource to make information available to teachers already in the classrooms. The results from the evaluation form indicate that as a result of the additional pedagogy module pre-service teachers are now more familiar with misconceptions, and of the different strategies that can be used to identify and reduce them in the classroom. Here, it is important to interpret these findings as indicators rather than results due to the differential power relations between the author (tutor) and pre-service teachers.

Phase three of this investigation involved the development of lesson guides. These lesson guides were designed by incorporating a conceptual change approach. The new demands of changing information, technologies, jobs and social conditions cannot be met through passive, rote learning focused on basic skills and memorisation of disconnected ideas. The lesson guides were used by pre-service teachers to teach senior cycle students while on their fourth and final year of teaching practice. A pre and post identification
instrument was developed which consisted of two tiered multiple choice questions, open ended questions and diagrammatic representations. The findings indicate that the experiment groups’ conceptual understanding was significantly better than the control groups which were taught using a didactic approach. The effectiveness of the website was evaluated using a likert scale and indicated that the website was a useful and valuable resource.

Effective and evidence-informed pedagogic practices are clearly needed by all teachers, and students, to identify, overcome and ultimately eliminate misconceptions in the acquisition of accurate scientific knowledge. One way of improving the quality of teachers in this regard can be achieved by targeting pre-service teachers, ensuring that they have capacity to continually interrogate their misconceptions, while working alongside peers and teacher educators to recognise and reduce, if not completely remove, Biology misconceptions. This study suggests the need for broad-based conceptual toolkits of knowledge, supports and pedagogical practices along the lines of a ‘good enough’ model of teaching. The findings have implications for teacher education, from initial teacher education through to in-career teacher development.
Declaration

DECLARATION

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Declaration

I hereby declare that this project is entirely my own work, other than the counsel of my supervisor, and that it has not been submitted for any academic award, or part thereof, at this or any other educational establishment. Where use has been made of the work of other people it has been fully acknowledged and referenced.

__________________________________   _______________________
Elaine Galvin (Author)     Date
Dedication

I would like to dedicate this dissertation to my family (my parents and my sisters; Karen, Lynda and Lorraine) and my boyfriend Micheál. Thank you all so much for your unwavering support, encouragement and patience with me throughout this journey.
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I would like to thank my supervisor Dr. Audrey O’Grady who has been incredibly generous with her time and wisdom and given me her continuous guidance, support and encouragement. Thank you for the opportunity to work with you; it has been my pleasure. You’re an inspiration for any young lady embarking on an academic journey.

I would like to thank and acknowledge all of the teachers, pre-service teachers, students and schools that took part in the study. Thank you for all your time and patience.

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A big thank you to all my family for being so supportive, in particular I want to thank Mam and Dad for all the prayers and candles. Your dedication to the cause is overwhelming. Thanks to my sisters, I know I haven’t been easy to put up with.

Finally, I would like to thank Micheál for everything. Thanks for the laughs and cuddles; couldn’t have done it without you.
## Abbreviations

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<td>Association of Secondary Teachers Ireland</td>
<td>ASTI</td>
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<tr>
<td>Cognitive Acceleration through Science Education</td>
<td>CASE</td>
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<tr>
<td>Continual Professional Development</td>
<td>CPD</td>
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<td>Deoxyribonucleic Acid</td>
<td>DNA</td>
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<td>General Certificate of Secondary Education</td>
<td>GCSE</td>
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<td>Information Communication Technology</td>
<td>ICT</td>
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<td>Initial Teacher Training</td>
<td>ITT</td>
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<td>Irish Science Teachers Association</td>
<td>ISTA</td>
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<td>Junior Certificate Science Syllabus</td>
<td>JCSS</td>
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<td>Multiple Choice Questions</td>
<td>MCQ</td>
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<td>National Council for Curriculum and Assessment</td>
<td>NCCA</td>
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<td>National Research Council</td>
<td>NRC</td>
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<tr>
<td>Organisation for Economic Co-operation and Development</td>
<td>OECD</td>
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<td>Pedagogical Content Knowledge</td>
<td>PCK</td>
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<tr>
<td>Professional Development Service for Teachers</td>
<td>PDST</td>
</tr>
<tr>
<td>Programme for International Student Assessment</td>
<td>PISA</td>
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<tr>
<td>Science Reflective Journals</td>
<td>SRJ</td>
</tr>
<tr>
<td>Science Teachers Association of Nigeria</td>
<td>STAN</td>
</tr>
<tr>
<td>Science, Technology, Engineering and Maths</td>
<td>STEM</td>
</tr>
<tr>
<td>Scientific Thinking Enhancement Project</td>
<td>STEP</td>
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<tr>
<td>State Examinations Commission</td>
<td>SEC</td>
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<tr>
<td>Statistical Package for the Social Sciences</td>
<td>SPSS</td>
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<tr>
<td>Teachers Union of Ireland</td>
<td>TUI</td>
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<td>Teaching and Learning International Study</td>
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Chapter 1: Introduction

Teacher education has undergone many changes in the recent past and there has become a far greater emphasis on using empirical research and new findings from the literature, mostly from psychology literature, as the way forward. None the less the great debates in education in relation to the purposes of education and the multiple and complex roles and responsibilities of teachers have not abated and continue to inspire the philosophy and sociology of education (Apple 2012; Biesta and Miedema 2003). While political systems of education across the western world continue to press for a ‘technology of teaching’ as skills and competences and pre-defined dispositions for cognitive improvement and literacy learning and, ultimately national economic competitiveness, many educationalists and theorists argue for broader social, moral and political aspects of teaching and education (Sexton 2007). This study in science teacher education focuses on just one aspect of the teachers’ role that is cognitive development in young people in upper secondary school. The study examines and explores conceptual development in young people with a view to increasing the specialist knowledge base in this regard and improving the accurate acquisition of science content knowledge among student teachers, at the university, and among experience science teachers in the schools. While the study is focused in one university in the Republic of Ireland it will have relevance outside of Ireland and in the wider research literature.

1.1: Motivation for the Study

Misconceptions in Science have been found to be a large contributor to students’ level of understanding at primary (Mikkila-Erdmann 2001), secondary (Boomer and Latham 2011; Yenilmez and Tekkaya 2006) and third level (Ahtee and Varjola 1998; Ross et al 2010; Russell et al 2004). Despite this, the research into misconceptions in Biology is limited,
particularly in Ireland. Current research in the Sciences has indicated that teachers can contribute to the presence of misconceptions in their students (Burgoon et al. 2011; Kapyla et al. 2009; Krall et al. 2009; Partosa et al. 2013; Yip 2007).

Senior cycle Biology is one of the most popular subjects taken by students in Ireland and is the most popular of the three Sciences (State Examinations Commission 2013); however, this subject relies heavily on rote learning and it appears that deeper levels of understanding are rarely tested (Donnelly 2014). This can result in a serious level of misconceptions when students arrive at higher education, and according to lecturers of the Sciences in the University of Limerick it has contributed to poor grades in introductory Biology modules, for example the process of diffusion and osmosis (Odom and Barrow 2006).

Misconceptions are a major concern among researchers in Science Education as a student’s ability to learn new scientific information depends greatly on the students’ pre-existing beliefs (BouJaoude 1991). It is this knowledge that determines what new knowledge they can construct and retain, therefore what they already know about a topic may either enhance or hinder their learning of the correct body of knowledge (Sewell 2002). Despite the large number of students taking Biology at senior cycle (approx 60%), there has been no comprehensive study on misconceptions in Biology in Ireland; this is despite a number of important international studies (Abell 2008; Luera et al. 2005; Sullivan-Watts et al. 2013). It is vital that students and educators alike are assessed, and learn how to diagnose and assess themselves, to determine these misconceptions so that they can continue to be recognised, reduced and ultimately overcome (Burgoon et al. 2011; Lim and Lee 2014; Yip 2007). In addition, many core textbooks have contributed to the
formation of misconceptions among both students and teachers (Angell et al. 2005; Kose et al. 2009).

Despite many students having top Leaving Certificate grades, they often arrive into third level education with very poor content knowledge. It is imperative that the standard of students entering higher education is improved, by overcoming misconceptions and tackling rote learning. Results from a pilot study (Galvin and O’Grady 2012) looking at the number and levels of misconceptions held by students, service teachers and pre-service teachers has provided some alarming results. The participants showed some very serious misconceptions in fundamental Biology topics. There is need for innovative pedagogical approaches to overcome conceptual misunderstandings and implications for improved dialogical models of teacher continuing education including school-university partnership approaches (Mooney Simmie 2007). These partnerships need to be set, not within functional models of teacher education, but within extended forms of professional development so that teachers can remain constantly connected with subject matter knowledge as well as the scholarship of teacher education into the future. This expansive way of looking at teacher education as a continuum is supported by empirical findings in a study in New Zealand by Timperely et al. 2007 and flies in the face of more mechanistic and technical practices.

1.2: Research Design and Objectives

This study took place in the University of Limerick, it involved student teachers from their second and third year (n=154) of teacher education, experienced Biology teachers (n=45) and senior cycle students (n=1,315) from forty seven secondary schools around Ireland. The purpose of this investigation was to 1) identify misconceptions in Biology that senior cycle students, pre-service teachers and qualified teachers hold, 2) to research how
individuals learn information and what influences or underpins their learning 3) to
determine what contributes to the formation of these misconceptions and hence 4) develop, implement and evaluate cited conceptual change strategies that might help to
recognise, reduce and ultimately remove the complex problem of misconceptions in the
learning and understanding of the particular topics for students and teachers in Ireland.
The main literature in the conceptual framework looked at the complexity of learning and
effective teaching, the importance of continual professional development as well as the
challenges of school culture. This is a complex and difficult area of science teacher
education, in which the author tried to find useful conceptual tools and practices to create
awareness and to scaffold and support the acquisition of accurate scientific disciplinary
knowledge.

The research was carried out in three phases. The first phase was to determine Biological
misconceptions held by service teachers, pre-service teachers and senior cycle students
throughout Ireland using a diagnostic instrument. As well as examining Irish Biology
textbooks for ways in which they could contribute to the formation of misconceptions. The
second phase of the research was to devise an intervention programme to recognise,
reduce and ultimately remove these misconceptions, through the development of an
additional pedagogy module and Biology website (Appendix 31) for pre-service teachers
in the University of Limerick. In phase three the pre-service teachers who participated in
the pedagogy module implemented some of the conceptual change strategies taught and
the effectiveness of these resources and strategies in developing students’ conceptual
understanding were analysed and evaluated using a pre and post identification instrument.
1.3: Research Questions

We hypothesise that there are serious misconceptions held by people at all levels of Science education, inclusive of teacher educators. These misconceptions have developed for a number of reasons; teachers’ lack of awareness and exploration of students’ prior knowledge, outdated and misleading texts and diagrams in textbooks, teachers’ inadequate subject matter knowledge and poor explanations and the pressures of school culture. The following research questions were developed in order to test these hypotheses.

1. To what extent do senior cycle students, pre-service and qualified teachers hold misconceptions in Biology and what misconceptions are the most prevalent?
2. How can conceptual change be incorporated effectively in the Science classroom?
3. What implications does conceptual change have on the design of curricula and instruction?
4. What challenges does school culture present for learning, teaching and continual professional development?

1.4: Significant Contribution

Understanding the nature of conceptual change, and how to encourage and direct it, has been a major concern in research in science education (Taber 2009). The classical approach for conceptual change to occur in science education trying to replace or eliminate misconceptions by new and better science conceptions is fundamentally misleading (Posner et al 1982). Conceptual change in science learning is a slow and gradual process (Carvita and Halden 1997), learners are not like scientists in that they do not understand that their beliefs are hypotheses that need to be tested (Vosniadou 2003); that affective and motivational factors have an important role in conceptual change (Treagust and Duit 2009) and that conceptual change is significantly influenced by social, historical and contextual processes (Hatano and Inagaki 2003; Taber 2009).
Teachers are central agents of change in schools (Lang 1999). Notwithstanding the influence of factors such as socio economic status, home and community, student learning is strongly influenced by what and how teachers teach. The way teachers teach is influenced by the teachers’ subject matter knowledge and their beliefs about what is important to teach, how students learn, and how to manage student behaviour and meet external demands (Darling Hammond and McLaughlin 1995; Timperley 2008). Theory and practice need to be integrated and continually interplay together in the work practices of teachers. In this way we are talking about the development of thinking teachers enacting thinking practices and eliciting conceptual change and thinking in their students understanding of science and biology topics. In effective and person-centred professional development, theories of curriculum, effective teaching and assessment are developed alongside their application to practice and teachers and teacher educators find new places and spaces for meaning-making and dialogue in relation to the science curriculum. A skills-only focus does not develop the deep understandings teachers need if they are to change practice in ways that meet the complex demands of everyday teaching. Sustained improvement in student outcomes requires that teachers have sound theoretical knowledge, evidence informed inquiry skills and supportive organisational conditions (Timperley 2008). Integration of misconceptions into the pedagogy module of pre-service Science teachers should provide them with the knowledge, awareness and skills to help them recognise and challenge their own and their students’ misconceptions in the different senior Biology topics (Driver et al 2014). An intervention programme should aim at promoting the awareness of teachers to students’ learning difficulties, developing their professional skills in facilitating students’ restructuring of concepts and provide a support network between the author and pre-service teachers.
The search for and development of a curriculum of partnership (Lawlor et al. 2009) whereby continuous collaboration and partnerships occurs between service teachers, pre-service teachers, and third level teacher educators as a source for bridging the gap between theory and practice in teacher education and for educational reform (Little 1993). Curriculum innovation has become increasingly mandated and controlled by accountability measures (Ball 2012). Public accountability is a new kind of taylorism reducing students into numerical objects whereby they are continuously compared (Au 2011). When done well however these partnership models do have the potential to uplift teacher education and to move it toward an intellectually challenging and inspiring practice for all (Young et al. 2015).

Structurally, teacher education in Ireland has undergone significant reform in order to conform to European education policies; however significant gaps remain in the existing teacher education policy particularly in relation to continuous professional development which may, if not addressed, impede Ireland’s capacity to adequately prepare teachers for the challenges of the twenty-first century (Harford 2010). Traditional notions of in-service training need to be replaced by opportunities for ‘knowledge sharing’ (Darling Hammond 1998). Teachers need opportunities to share what they know, discuss what they want to learn and provide time for research and inquiry, for trying and testing, for talking about and evaluating the results of learning and teaching (Darling Hammond and McLaughlin 1995).

Science professional development should address teachers’ needs as learners along with building on their current existing knowledge of Science content, teaching, and learning
Long-term professional development programmes are clearly needed to achieve lasting changes in teachers’ specialist knowledge base. Teachers need greater exposure to learners’ misconceptions in order to realise the importance of this area of practice (Domingos-Grilo et al 2012). The identification of misconceptions in Biology is essential for learning to be developed and advanced (Hodgson and Pyle 2010). The website is a useful tool for both pre-service and qualified teachers to access the theory on conceptual change, collaborate ideas with other teachers, reflect on their teaching and learning and recognise the common misconceptions that students could have in a particular topic.

This is an area of science teacher education that is fraught with complexity and difficulty and there is no one simple, technical solution that is going to re-culture schools and colleges in ways that give easy answers. This study aims to examine improvement in one important aspect of the teachers’ habitus and it is not intended as a catch-all approach for the broader educative purpose of education, teaching and learning.

1.5: Overview of the chapters

Chapter 2 – Setting the Context

This chapter explores Biology as a science subject at post-primary/secondary education, called second level education, in the Republic of Ireland. The role that Science and Biology plays in the development of a sustainable Economy is discussed, as the political imperative for change driven from Ireland national economic agenda, along with the performance of Irish students in the Irish State Examinations and International studies. The impact of school culture and reform on teachers teaching and students’ learning is also explored as well as the value of Continual Professional Development (CPD).
Chapter 3 – Literature Review

This chapter explores the highly contested construct of learning in the literature. It looks at learners’ methods of acquiring new information and the processing of it. It defines what misconceptions are and what may contribute to their formation. The information in relation to misconceptions is scrutinised to consider the sources of misconceptions and how they affect new learning. The internationally recognised misconceptions in Biology are also reviewed. Methods cited within the literature to recognise, reduce and remove misconceptions and achieve conceptual change are examined. Finally the challenges and benefits of continual professional development and the desire for school-university partnerships are documented.

Chapter 4 – Materials and Methods

This chapter provides a detailed description of the how the three phases of this research investigation were carried out. It identifies how the data was organised and analysed. Descriptions of the sample groups that participated in the study are also outlined.

Chapter 5 – Results and Analysis Phase 1

This chapter is the first of three results chapters, it outlines the results obtained from the paper and pencil identification instrument completed by the senior cycle students, pre-service and service Science teachers for phase one of this investigation. It gives a detailed description of the main findings of the three groups with respect to; gender, age, year of study, grades obtained in state examinations, level studying at and type of secondary school attended.

Chapter 6 – Results and Analysis Phase 2
This chapter is the second of three results chapters, and provides a comprehensive analysis of phase 2 of the research. The chapter analyses and discusses the findings from the development and implementation of the additional (voluntary) pedagogy module.

Chapter 7 – Results and Analysis Phase 3

This chapter is the final results chapter which draws together data from; the pre and post identification instrument distributed to the experiment and control group students, interviews completed by third year pre-service teachers and an evaluation form to assess the effectiveness of the website resource for its members.

Chapter 8 – Discussion

This chapter looks at the key findings from the three phases of the research. Elements of the three phases of results are brought together and discussed in the context of the research questions. New knowledge from the study is explored along the lines of a ‘good enough’ model of science teacher education.

Chapter 9 - Conclusion

This final chapter summarises the main conclusions drawn from the study. The author discusses the research contributions this study has made to Science Education. Recommendations are suggested based on the findings from the study and ideas for future research work, and some new research questions, are proposed.

1.6: Publications Arising from Study

The author has published two papers titled “To determine and overcome Biological misconceptions held by students and Educators in the Irish Schooling system” in New
Chapter 2: Setting the Context

2.1: Introduction

This chapter provides an overview of the Irish Education system with a particular focus on senior cycle Biology, as this study focused predominantly on this sample group for phase 1 and phase 3. Misconceptions develop in students at a young age, therefore the different Biological concepts that students encounter from primary to secondary are highlighted. The performance and uptake of Irish students in relation to Biology is assessed using data relating to senior cycle examination results from the State Examinations Commission.

The shape of the teaching profession in Ireland is outlined. This study requires pre-service teachers (second and third years) and service Biology teachers to engage in continual professional development to achieve benefit from this intervention, therefore the contested nature and complex challenges that continual professional development brings and the importance of it to the effectiveness and expansiveness of teachers’ teaching and learning is explored. In addition, the complexity of school culture and recent reform on teaching, learning and continual professional development with particular emphasis on senior cycle Biology is considered.

Finally, as small scale studies in the University of Limerick found that state examinations were not found to be a good indicator of students conceptual understanding the author looked at how students performed in Science with other forms of testing in comparison to International standards. The importance of Science and Biology to the Irish economy is highlighted and emphasises the impact that economy demands has on education.
2.2: The Irish Education System

The Irish Education System consists of three main levels; primary education (first level), secondary education (second level) and higher education (third level). The state funds all three levels of education in what is called a state-aided system. The Church owns the majority of primary and secondary schools (mostly the Catholic Church) and their ethos for the spiritual and moral development of young people is assured in the Education Act 1998. It is compulsory for children to attend education from the age of 6-16, or until the child has completed three years of second level education. Figure 2.1 provides a detailed account of the Irish Education System. Irish children spend 8 years in primary education before proceeding with their secondary education. Secondary education is divided into two cycles; junior cycle and senior cycle. Junior cycle consists of 3 years with an optional transition year at the end of the third year. Senior cycle is a further 2 years, which equips students for entry to third level education (Department of Education and Science 2004). Studying Science is now a crucial aspect in both the primary and secondary curricula.

2.2.1: Primary School Science

A new Science curriculum for primary level education was introduced in 1999 and became compulsory in 2003 with the goal to provide a more learner-centred environment with an emphasis on literacy, numeracy and language (National Council for Curriculum and Assessment 2003). The primary Science syllabus is called Social, Environmental and Scientific Education. The Biology subject content of primary Science includes an introduction to Ecology where students learn about the range of plants and animals found in local and wider environments. Students explore different species of animals and the adaptations they undergo in their environment. Students learn about the human being; vital internal and external organs, the breathing system and the skeleton. Students practice
healthy eating and learn of the benefits it brings to them in relation to growth and energy for exercise. Common misconceptions at this level are; a tree isn’t a plant and food is anything a human or plant takes in (Driver et al 2014). Children develop Science misconceptions at a very early age (Smolleck and Hershberger 2011). In primary school they can hold a number of misconceptions about Science constructed from their experiences inside and outside school (Driver et al 2014). These ideas that they hold can be deeply rooted and the teaching of the correct scientific concepts is unlikely to be effective unless the teachers take the learners previous perspectives into account during instruction (Driver et al 2014).

When Science was made compulsory in primary schools, the majority of primary school teachers had not taken a Science subject to upper secondary level (Task Force 2002). Without this fundamental knowledge, teachers find it difficult to successfully deliver the appropriate Science lessons and experiences effectively to their students (Engineers Ireland 2010). A number of Science initiatives have been implemented since to support Science for primary level teachers for example ‘Come to your senses programme’ which is run by the Royal College of Surgeons Ireland. The Royal College of Surgeons and Discover Primary Science and Maths have delivered workshops to introduce the teachers to alternative, hands on and inexpensive ways of teaching Science (Royal College of Surgeons 2012).
Figure 2.1 The structure of the Irish Education System (Department of Education and Science 2004)
2.2.2: Secondary School Science – Junior Cycle Science

Ireland is the only country among 21 European nations that doesn’t have Science as a compulsory subject to lower secondary (Smyth and Hannon 2006). On average 88% of Irish students study Science for their Junior Certificate. It has been noted that Science should become a compulsory subject at Junior Certificate level (Taskforce 2002). This would ensure that all primary school teachers going forward would at least have this basic knowledge to enable them to teach these topics to their students.

Table 2.1 Biology topics and concepts covered at Junior Certificate Level

(National Council for Curriculum and Assessment 2003)

<table>
<thead>
<tr>
<th>Human Biology – food, digestion and associated body systems</th>
<th>Human Biology - the skeletal/muscular system, the senses and human reproduction</th>
<th>Animals, plants and micro-organisms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food</td>
<td>Skeletal system</td>
<td>Living things</td>
</tr>
<tr>
<td>Digestion</td>
<td>Muscular system</td>
<td>The Microscope</td>
</tr>
<tr>
<td>Enzymes</td>
<td>Sensory system</td>
<td>Plant Structure</td>
</tr>
<tr>
<td>Aerobic respiration</td>
<td>Reproductive system</td>
<td>Transport in Plants</td>
</tr>
<tr>
<td>Circulatory system</td>
<td>Genetics</td>
<td>Photosynthesis</td>
</tr>
<tr>
<td>Excretion</td>
<td></td>
<td>Reproduction and germination in plants</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ecology</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Microbiology and Biotechnology</td>
</tr>
</tbody>
</table>

The aim of the Junior Certificate Science course is to introduce, in more detail, aspects of human and plant Biology. Students study a variety of systems that carry out a range of functions as well as the importance of plants and micro-organisms in the world. Students are also introduced to microbiology and biotechnology. The syllabus is intended to be activity based in its design and to emphasise the practical experience of Science in all domains (National Council for Curriculum and Assessment 2003). Teachers need to provide opportunities for students to participate in argumentation and discussion with their peers to express their own ideas. It creates an environment in which students can clarify
their own notions and identify misconceptions they hold (Driver et al 2014). Examiners expressed that the increased number of questions in the examination requiring students to engage with and use higher order skills has made the examination particularly challenging (State Examinations Commission 2010). This greater emphasis on higher order thinking should eliminate rote memorisation and help address misconceptions that are deeply rooted from previous primary Science education.

2.2.3: Secondary School Science: Senior Cycle Biology

According to the Department of Education, the Biology syllabus aims:

- To contribute to students' general education through their involvement in the process of scientific investigation and the acquisition of biological knowledge and understanding.
- To encourage in students an attitude of scientific enquiry, of curiosity and self-discovery.
- To develop an understanding of biological facts and principles
- To enhance an interest in and develop an appreciation of the nature and diversity of organisms.
- To create an awareness of the application of biological knowledge to modern society in personal, social, economic, environmental, industrial, agricultural, medical, waste management and other technological contexts to develop in students an ability to make informed evaluations about contemporary biological issues.

(National Council for Curriculum and Assessment 2003)

The material in the senior cycle Biology Syllabus covers the main areas of Biology. The Biology topics that students study during the two years of senior cycle are listed in Table 2.2.
Table 2.2 List of Senior Cycle Biology Topics

<table>
<thead>
<tr>
<th>Senior Cycle Biology Topics</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Unit 1: The Study of Life</strong></td>
</tr>
<tr>
<td></td>
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<td></td>
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<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Unit 2: The Cell</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Unit 3: The Organism</strong></td>
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</tbody>
</table>

Students are assessed at the end of two years of study in the senior cycle examination and they can either sit a higher or ordinary level Biology paper.

2.2.3.1: The Uptake and Performance of Students Studying Biology as a Senior Cycle Subject

![Figure 2.2 The uptake of Senior Cycle Science subjects from 2002-2013 in Ireland](image-url)

Figure 2.2 The uptake of Senior Cycle Science subjects from 2002-2013 in Ireland
Biology continues to be the dominant senior cycle Science subject (taken by 59.7% of the cohort; four times as many students take Biology as take Chemistry and Physics) and the only Science subject in the top 10 subjects in Ireland. From 2002, since the new syllabus has been introduced, the uptake of Biology has increased from 37.7% of the total cohort to 59.7%. In addition, more students are taking the higher level exam paper than previous years, 2013 saw 74.4% of the cohort taking the higher level with 25.6% taking the ordinary level paper.

Table 2.3 Senior Cycle Science uptake (% of total cohort)

<table>
<thead>
<tr>
<th>Year</th>
<th>Biology</th>
<th>Physics</th>
<th>Chemistry</th>
<th>Ag Science</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>53.1</td>
<td>14.2</td>
<td>14.2</td>
<td>9.5</td>
</tr>
<tr>
<td>2009</td>
<td>54.1</td>
<td>13.3</td>
<td>14.3</td>
<td>9.6</td>
</tr>
<tr>
<td>2010</td>
<td>53.7</td>
<td>12.4</td>
<td>13.9</td>
<td>10.6</td>
</tr>
<tr>
<td>2011</td>
<td>55.8</td>
<td>12</td>
<td>14.1</td>
<td>11.9</td>
</tr>
<tr>
<td>2012</td>
<td>54.7</td>
<td>11.4</td>
<td>14.5</td>
<td>12.3</td>
</tr>
<tr>
<td>2013</td>
<td>59.7</td>
<td>12.2</td>
<td>15.45</td>
<td>14.05</td>
</tr>
</tbody>
</table>

Biology is predominantly taken by females, although over the five years examined the gap has narrowed between the female/male ratios, Table 2.4.

Table 2.4 Gender Composition of Higher and Ordinary Level Cohort

<table>
<thead>
<tr>
<th>Year</th>
<th>Total Higher Level</th>
<th>Total Ordinary Level</th>
<th>Female as % of total Higher</th>
<th>Male as % of total Ordinary</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009</td>
<td>20102</td>
<td>7999</td>
<td>65.9</td>
<td>34.1</td>
</tr>
<tr>
<td>2010</td>
<td>20971</td>
<td>8278</td>
<td>65.2</td>
<td>34.8</td>
</tr>
<tr>
<td>2011</td>
<td>22676</td>
<td>7673</td>
<td>62.9</td>
<td>37.1</td>
</tr>
<tr>
<td>2012</td>
<td>22740</td>
<td>7801</td>
<td>61.8</td>
<td>38.2</td>
</tr>
<tr>
<td>2013</td>
<td>23433</td>
<td>8064</td>
<td>60.5</td>
<td>39.5</td>
</tr>
</tbody>
</table>

It is also evident from Table 2.5 that females have performed better than males with a higher percentage of the female cohort achieving an A, B or C grade than the male cohort.
### Table 2.5 Performance of Males & Females in Senior Cycle Biology

<table>
<thead>
<tr>
<th>Year</th>
<th>Male (% of Cohort that achieved ABC)</th>
<th>Female (% of cohort that achieved ABC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009</td>
<td>68.2</td>
<td>71.6</td>
</tr>
<tr>
<td>2010</td>
<td>69.5</td>
<td>71.3</td>
</tr>
<tr>
<td>2011</td>
<td>69.5</td>
<td>70.8</td>
</tr>
<tr>
<td>2012</td>
<td>68.7</td>
<td>73.9</td>
</tr>
<tr>
<td>2013</td>
<td>67.4</td>
<td>71.3</td>
</tr>
</tbody>
</table>

Regardless of gender, overall Irish students are achieving high grades in senior cycle Biology with almost 70% of the higher level cohort achieving an A, B or C grade and 58.5% of the ordinary level cohort obtaining an A, B or C grade, Table 2.6.

### Table 2.6 Overall performance of students in Higher and Ordinary Level Senior Cycle Biology

<table>
<thead>
<tr>
<th>Year</th>
<th>Higher Level</th>
<th>Ordinary Level</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% A</td>
<td>%A+B</td>
</tr>
<tr>
<td></td>
<td>14.4</td>
<td>16.7</td>
</tr>
<tr>
<td></td>
<td>41.7</td>
<td>44.4</td>
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<tr>
<td></td>
<td>69.6</td>
<td>71.1</td>
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<tr>
<td></td>
<td>8.2</td>
<td>8.4</td>
</tr>
</tbody>
</table>

Students perform well in aspects such as definitions of terms or details of Biological processes where the questions are looking for straightforward information. Students demonstrate a lack of deeper understanding if concepts are needed to be interrogated thoroughly. It is well documented in the state examinations that while progress has been made in recent years in students’ basic biological knowledge and understanding, students still lack specific knowledge of topics and struggle to explain, interpret and apply biological concepts using their higher order cognitive skills (State Examinations Commission 2013). Teachers need to be conscious of the formal operational thought required for such Biology topics and the challenges students may have when trying to teach them to them. It is the teachers’ role to structure the learning and experiences for
students in a way that will help them improve their conceptual understanding of the scientific concept (Driver et al 2014).

2.3: The Science Teaching Profession in Ireland

There are two modes of entry to the teaching profession in Ireland: consecutive and concurrent programmes of teacher education. The consecutive mode involves the study of Science to degree level followed by two years of teacher education. There are six institutions with consecutive Science second level initial teacher education programmes; Trinity College Dublin, Dublin City University, University College Cork, University College Dublin, National University of Ireland Galway, National University of Ireland Maynooth. The concurrent mode involves the simultaneous study of Science, Education and pedagogy over a four year degree programme. There are five institutions in Ireland with concurrent second level initial teacher training programmes in Science; University College Cork, University of Limerick, Dublin City University, National University of Ireland, Maynooth and St. Angela’s College Sligo. To date, there has been no research done on if the mode of entry to teaching; consecutive or concurrent affects the number of misconceptions a teacher holds. However, there has been research carried out in relation to Chemistry misconceptions (Sheehan 2010) and there was no statistical significant difference found between mode of entry to teaching and percentage of misconceptions held. In this study there were pre-service teachers from concurrent Science degree programmes and service teachers from concurrent and consecutive modes. A good number of science teachers in Ireland, since 1961, have remained members of a voluntary network called the Irish Science Teachers’ Association (ISTA) which holds an annual conference and publishes a journal, called Science, to update members on developments on all aspects of science education.
2.3.1: The Teaching Council

The Teaching Council established as a result of the Teaching Council Act 2011, on a statutory basis since 2006, is in charge of regulating the teaching profession in Ireland. The council promotes professional standards in teaching and ensures the reputation and status of the teaching profession is continuously enhanced and is responsible for public accountability of the profession (The Teaching Council 2014). The Teaching Council highlights the value and importance of CPD for schools and teachers by ensuring it is ongoing and sustained (Gleeson 2012). Irish secondary school teachers have two unions that aim to enhance their working conditions and prioritise the teachers’ status and have been generally successful in this regard: Association of Secondary Teachers of Ireland and The Teachers Union of Ireland.

2.4: Continual Professional Development

Society is constantly changing and schools need the skills and knowledge to change with it and teachers’ clearly need to change as well in their pedagogical assignment and particularly in their modes of instruction (Biesta and Miedema 2003). It is particularly these modes of instruction, and how they assist the diagnosis of misconceptions in biology education, that is of particular interest in this doctoral study. Nowadays, the state has defined the changes that need to happen, but there is increasingly less inputs and resources for the types of expansive partnership activities needed to do this work well and in educative ways that support deep, rather than surface change (Mooney Simmie and Lang 2012). In today’s diverse schools there are many challenges that schools and teachers need to respond to; student background and culture, students’ physical and mental disabilities and the variation in learning abilities (Leithwood and Riehl 2003).
Continual Professional Development (CPD) refers to activities aimed at enhancing the knowledge and skills of teachers by providing them with direction, education, scaffolding and support. It is likely to affect their attitudes and approaches which will contribute to the improvement of the quality of learning and teaching processes (Lessing and de Witt 2007). CPD can assist teachers become more competent in their subject matter knowledge and confident that they have the power to influence and make a difference in their students’ achievement (Cordingley et al 2005). The 1991 and 1995 OECD report signalled the need to develop policies, strategies and structures that would help strengthen in-service courses available to teachers, as at the time the number and resourcing of in-service courses was inadequate (Sugrue and Thuama 1997).

The CPD courses available to teachers are predominantly to do with school planning, whole school and staff development, facilitation of special needs students and bullying (Sugrue and Thuama 1997). The subject content in CPD courses is more examination focused than learner centred (Mooney Simmie 2007), teachers are merely being “coached to the exams” (Gleeson 2012). The majority of courses are run during school breaks and participation is the sole responsibility of the teacher. Some research suggests that CPD workshop facilitators need to improve the activities and presentation of the material to increase the uptake of teachers attending them, the workshops need to enhance teachers’ enthusiasm and facilitate a ‘hands on’ approach (Carlgren 1999). CPD needs to empower teachers with the necessary confidence, skills, knowledge and support to strive in their teaching. It is important that teachers are given the opportunity to experiment with their ideas in the classroom in order to evaluate and reflect on their progress and to make the necessary professional judgements required of an ever changing practice and a practice where formative assessment needs to become a key component in professional
development. It is well documented that teachers may hold similar misconceptions to their students’ misconceptions therefore, it is important to provide opportunities for teachers to address their own before they can assist students with theirs (Driver et al 2014). There is a need for a shift from the old models of “teacher training” or “in-servicing” to a model, in which teachers confront research and theory directly, are regularly engaged in evaluating their practice, and use their colleagues for mutual assistance (Darling Hammond 1998).

Pre-service teachers need supports in becoming thinking teachers, such as, access to meaning-making opportunities and personnel, including other teachers, teacher educators and researchers, as well as the development of a wide repertoire of pedagogical strategies (Ameyaw and Sapong 2011; Driver, Newton and Osborne 2000; Keys and Bryan 2001). Teachers’ development needs appeared as important as efforts made in building a knowledge base of science content and pedagogical knowledge (Burgoon et al 2011). There needs to be greater focus placed on the continuum of teacher education, ITE, induction programs and in-career development (Luft et al 2003). Although the identification of misconceptions an important initial step towards better science education, knowledge of the causes and processes is essential for designing and constructing effective pedagogical strategies (Kose 2008). Reflection about teaching is an important part of pre-service teachers’ development (Penso et al 2001). Teachers that develop awareness of their students prior beliefs are well placed to support their students in the necessary cognitive dissonance required for cognitive development in this regard (Driver et al 2014).

Being a teacher is not an easy task, especially when confronted with the many complex demands of everyday life (Biesta and Miedema 2002) and over the course of their careers teachers encounter endless change (Hargreaves 2004). In order for professional
development to have an impact on the teacher and school as a whole it needs to become a continuous and expansive process (Lessing and de Witt 2007). Too often, courses offer only short term support, teachers need to be surrounded with a professional culture that supports teacher learning and teacher education (Feiman Nemser 2003). Teachers need to move away from the traditional role of transmitter of information and become a learner and facilitator of knowledge and understanding and an experimenter of teaching in their own classroom settings (Darling-Hammond and Mclaughlin 1995). Continuing development and learning for teachers should not end at graduation; teachers should see themselves as lifelong learners to ensure personal and professional development throughout their careers (Cordingley et al 2005; Darling-Hammond and Mclaughlin 1995). It is crucial to allow teachers time to sustain the CPD and enable them to embed the concepts and practices they have learned into their own classrooms (Cordingley et al 2005). It is timely that Biesta (2012) and others are challenging this discourse of learning and, as philosophers of education, are concerned with the disappearance of education and teaching from policy discourses and their replacement with what he calls an ‘empty discourse of learning’. Within this empty rhetoric there is a real danger that the teacher will spend more time trying to satisfy the ‘how’ and ‘what’ of teaching rather than the reflective and challenging work of ‘why’ and the generation of a sound rationale and thinking about their teaching and learning.

CPD courses that are subject specific are required as teachers need to be equipped and supported to respond effectively to changes in their subject syllabus, teaching methodologies, assessment and department organisation and collaboration. Science needs to intrigue teachers and students; therefore it must be taught in a stimulating, imaginative and creative way (Mooney Simmie 2007). A shift towards a more interactive and
collaborative professionalism is essential, teachers must become more proactive in their teaching and learning (Surgue and Thuama 1997). Working with teachers in empowering them to design, to learn and to change develops the teaching of the subject and the leadership capacity of the teachers themselves (Mooney Simmie 2007). Experienced teachers need to show support and guidance by providing more than social support to new teachers (Kirkwood 2001). New teachers want to learn how to implement the curriculum in a successful and fruitful manner, how to best address specific students needs and to gain an insight into the best way to teach specific topics of the syllabus (Johnson and Kardos 2002). Experienced teachers should help new teachers to develop safe classrooms, participation of students in worthwhile learning and create effective assessment techniques to evaluate their students understanding (Feiman Nemser 2003). Teachers that are aware of common prior ideas will be better able to help students open their mind to new experiences and cognitive development (Driver et al 2014). However, if this is to be achieved schools need to radically alter the structures they have in place, allow more time for curriculum development (Bryant et al 2001) and encourage collaboration to ensure the CPD is successfully implemented and worthwhile doing (Duncombe and Armour 2004). The new demands of changing information, technologies, jobs and social conditions cannot be met through passive, rote learning focused on basic skills and memorisation of disconnected ideas (Barron and Darling Hammond 2008; Lehane et al 2013).

2.5: School Culture and Reform

The school culture of Irish schools is dominated by measurability and performance (Ball 2012; Callan 2006). This shift in educational ethos has a significant impact on the pedagogy methodologies used; it challenges the development of students’ cognitive, effective and psychomotor domains. The teachers are forced to take a didactic teacher
centred approach with the majority of the content delivered lower order in nature (Hennessy et al 2011). Teachers’ misconceptions are known to have a significant influence on student’s acquisition of accurate knowledge (Kapyla et al 2009; Krall et al Wymer 2009; Partosa et al 2013). Studies show that science teachers need effective ways to confront their own misconceptions before they can effectively assist their students in this regard (Allen 2014; Burgoon et al 2011; Lim and Lee 2014; Yip 1998, 2007). However, many teachers due to the demands of curriculum and time constraints are compelled to seek short cuts and do not pay sufficient attention to students’ misconceptions (Chen et al 2006). When teachers underestimate the effect of misconceptions students’ learning of scientific knowledge may be negatively impacted (Ravanis and Bagakis 1998; Stepans and Kuehn 1995). Similarly, in initial teacher education it is the role of the teacher educator to help pre-service teachers diagnose, reduce and ultimately eliminate misconceptions. A number of studies show that it can be challenging for teachers to enact effective pedagogical strategies, inquiry-oriented and active learning practices, and to receive appropriate supports and guidance, such as, open access to research literature and multiple networks of support and partnership (Ruohotie-Lyhty and Moate 2014; Opfer and Pedder 2011). Students need to be given opportunities to express their learning and understanding (Lynch and Wolcott). The great emphasis on the summative examination, which is governed by the amount of points one attains, creates a pressurised environment for both the teachers and their students resulting in a significant constraint towards the development of creative pedagogies (Gleeson 2012). Teachers are forced to teach towards the exam rather than taking a holistic approach to the learner as suggested by the curriculum (Gleeson 2012). Implementing a pedagogy that allows for creativity and innovation while still addressing the holistic development of the student will have its challenges (Hennessy et al 2011) but teachers need to acknowledge
that their role is more than ensuring they teach the students but to ensure that they learn (Vescio et al 2008). We need to recognise that the task of a teacher and the school is first and foremost a pedagogical task, as it is concerned with the whole person, the whole sense of identity of the student (Biesta and Miedema 2002).

O’Grady et al (2014) has conducted research which has displayed notable positive results on students’ achievement when active learning methods are employed as opposed to ‘traditional’ teaching methods. Active learning refers to students’ being allowed to take ownership of how to approach and progress a particular task or activity. Students are finding out for themselves as opposed to being handed information by the teacher (Kyriacou and Kunc 2007). However, despite the obvious benefits, teachers’ were still unconvinced of the methods. O’Grady et al (2014) indicates that this unwillingness on the part of both pre-service and existing teachers was a result of ‘cultural’ motives such as concerns with maintaining discipline and also the ability to foresee upcoming exam topics negated the effort for engaging in active learning. This suggests that the cultural, historical, and contextual constraints of engaging in this way of teaching consistently outweigh the benefit that might be gained from the evidence-based test results of students using active learning (O’Grady et al 2014). This research study adds to the mounting evidence from the contemporary literature that suggests that this ‘problem’ is one of teacher professional identity, teacher knowledge and school culture rather than simply a problem that requires functional technique or competence training. Newer types of scaffolding are clearly needed if conceptual change is to yield deeper levels of interaction, dialogue and critical thinking in the Biology classrooms (O’Grady et al 2014).
To ensure successful reform, professional development of teachers is crucial (Supovitz and Turner 2000). Teachers are reluctant to make changes that are governed by a top down approach as the support provided is insufficient (Spillane and Thompson 1997) resulting in increased anxiety and isolation associated with its implementation (Hargreaves 2004). The pressurised reform results in pedagogical barriers for teachers and limits opportunities for observations and experimentations. Teachers’ beliefs and values towards reform must be challenged and discussed for deep change to occur (Fullan 2007). The current climate needs students that are creative thinkers and aren’t afraid to become critically engaged in an area of Science they enjoy; however students have become experts at consuming knowledge rather than generating it (Hennessy et al 2011). It is important that teachers feel involved in curriculum implementation (OECD 2005) as they play a significant role in its success or failure (Tamir 2004). Teachers need to be encouraged to become committed to changing practices and possess a willingness to try new ideas that may enhance their teaching and student learning. Reform won’t be successful unless it is intensive and sustained (Supovitz and Turner 2000). Teachers need to be willing to make observations and allow other teachers to observe them as reflection and evaluation are key components to successful reform (Cordingley et al 2005; Darling-Hammond and Mclaughlin 1995; Vescio et al 2008).

Professional collaboration is low among Irish schools and when it does occur it deals with issues such as examination material, textbook selection or synchronisation of topics (Gleeson 2012). Creating a professional learning community among principal, year heads, home school liaison officers and teachers has a positive impact on teaching and student achievement (Lieberman and Miller 1999; Vescio et al 2008). Working collaboratively together will increase teachers’ professional knowledge and in return enhance students
learning as teachers become more aware of the importance of a student centred classroom (Thompson 2004). For teachers to be at the centre of change, policy makers need to rethink the way which schools are staffed, structured and managed. Time must be allocated for teachers to attend CPD and the sense of isolation among teachers must be overcome (Darling-Hammond and Mclaughlin 1995).

2.5.1: Junior Cycle Reform

The contested nature and challenges involved in reform is emphasised by the new Junior Cycle reform. They are not fully agreed at the moment due to an industrial dispute with the Teacher Unions that has gone on now for over a year, and involved two different Ministers for Education and Skills (Mooney Simmie 2015; Ryan 2015). Changes to the Junior Cycle were deemed necessary on two fronts firstly due to the ‘overcrowded’ nature of the curriculum and secondly due to the perceived overemphasis on the examination at the end of the third year (NCCA 2011). This reform hopes to improve the learning experiences of the students and remove the emphasis of rote learning in the classroom. The new Junior Certificate is very similar to high performing education systems like New Zealand and Finland (Flynn 2012). However, unlike New Zealand and Finland, Irish teachers are required to contribute a number of hours to supervision and substitution within their school. This reduces the time that could be spent on subject planning and development. In addition, the reduction in salary and increments reduces the value of the teaching profession (Teachers Union Ireland 2014). Teachers will need to be professionally equipped, engaged and educated in order for this reform to work. A new working group was developed by the Department of Education in 2014 which aims at addressing this issue. Such a reform will be challenging and the empowerment of the teaching profession is crucial to its success. Teachers need to be treated as professionals
and given the opportunity to develop innovative and argumentative lessons for their learners. It is essential that the working group assigned to this project provide the adequate resources, supports, guidance and pedagogy teachers need for this continuing professional development for this reform to work (Donohoe 2014).

Six ‘key skills’ have been identified as being important acquisitions for students, these are; managing myself, staying well, communicating, being creative, working with others, and managing information and thinking (NCCA 2011). It is suggested that these skills will facilitate the proposed changes to the assessment which has increased focus on students and those students taking ownership of their learning through creating, collecting and displaying proof of understanding, with feedback provided and progress recorded by teachers. Rather than students seeing themselves as passive absorbers of information, students will see themselves as actively engaged in constructing meaning by bringing their prior knowledge with them to take on new situations. Experiencing the phenomena for students is not enough; it is the sense that they make of it that counts (Driver et al 2014).

2.5.2: Senior Cycle Reform

Hyland (2014) reports on the design and content of the proposed new senior cycle Biology syllabus which focuses on the need for assessment and qualifications of students to be centralised. The reform proposes to incorporate a practical assessment worth 30%, which is recognised as a desirable change once it provides the reliability, validity, and transparency required for assessment of such a high stake exam as the Leaving Certificate (NCCA 2014). A radical renovate of the senior cycle exam needs to be undertaken in order to reflect the desired learning outcomes and discourage the practice of rote learning (Irish Science Teachers Association 2014). Without this change it is hard to imagine the desired shift to independent learning with students taking responsibility for their own
learning becoming a reality. In summary to implement the proposed Biology syllabus the schools require adequate laboratory access and resources, access to ICT and I.T. support, clarity on the depth of treatment for topics, time allocation and the meaning of learning outcomes (Moroney 2014) to enhance student and teacher engagement in the teaching and learning of Biology.

The current senior cycle Biology syllabus which is highly regarded by many Irish teachers needs to be updated and revised with new content added (Irish Science Teachers Association 2014). Reform is particularly necessary at the present time, given the advances in science and technology and the need for Irish students to be at the receiving end of the most engaging and up-to-date syllabus. However, there is a widespread view among teachers that the format and design of the current syllabus has worked well to date and that there is no need to change it (Moroney 2014; NCCA 2014). This further emphasises the challenges of school culture, the fears of teachers and how difficult it can be to implement change effectively and willingly.

The interactive materials, and links to relevant diagrams and literature provided in connection with the Biology syllabus, are indicative of the change that has occurred in teaching and learning in recent years. In coming to a decision about the reform consideration might be given to collaborating with other bodies, either nationally or internationally to provide appropriate materials, support, education, pedagogy and theory to implement this new syllabus effectively (Mooney Simmie and Lang 2013). Their expertise will help to bridge the gap between theory and practice, between the ideal and the possible (Darling Hammond 2007). Teachers, in particular, need to be brought deeper into these professional collaborations, they have an important role to play as they bring
knowledge of the school culture and classroom constraints to the discussion (Monsen 2003; O’Grady et al. 2014). Third level representatives and employers help to ensure that the revised syllabus prepare future students appropriately for further advancement in their learning and for working life. This proposed partnership model should serve Irish education well and help to overcome the challenges that they are faced with (Darling Hammond and McLaughlin 1995).

Another reform in recent months is the PDST have provided newly qualified teachers with an opportunity to engage in hands on practical inquiry based activities which are designed to reinforce the principles underlying the mandatory activities on the senior cycle Biology syllabus. Extension activities were also explored and implemented within the workshop. Pre-service teachers were addressed by experts in the field from different universities and provided an opportunity to integrate expert knowledge and theory with practical implementation. These type of partnerships and collaborations are desirable in the scaffolding of Biology reform and effective CPD (Department of Education and Skills 2014). The down side to this reform was there was certainly greater demand than supply, there were only two workshops carried out since November 2014 and so still teachers haven’t had the opportunity to partake and are on an endless waiting list.

2.6: The Importance of Science to the Irish Economy

Education policy is significantly linked to economic prosperity (Harford 2010). The need and desire to produce skilled and qualified individuals within the Irish workforce is always seen as a central issue in the development of a healthy, sustainable economy. Within the Irish government there are many departments and task forces associated with the achievement of this aim including the Higher Education Authority, Science Foundation
Ireland and Forfás. A central issue within this aim is the promotion and development of Science Education within the Irish economy in order to ensure a highly skilled workforce in this ever expanding and critical sector. The life Science industry in Ireland is viewed as particularly critical to the economy. A 2009 report by Forfás found that 30% (€44.4 billion) of Ireland’s total exports come from this sector which employs 52,000 people (Forfás 2009). These Science-based industries are equally important to the development and expansion of European and American economies as they rely on these exports (Owen-Smith et al 2002).

Another growing area found by Forfás as a critical contributor to Ireland’s economic growth is the development of a ‘Green Economy’ (Forfás 2011). A study by Forfás found that there was a requirement to produce skilled workers for the sub-sectors of the ‘Green Economy’ including environmental consultancy services, renewable energies, efficient energy use, and recovery and recycling. The importance of these Science based industries and sectors highlights the value of a high level of scientific competency at all levels of Irish education. The ability of the Science sector to assist Ireland’s economic growth is largely linked to the standard of the Irish education system and its ability to produce a high-quality workforce. The development of such skilled workers from our third level institutions firstly requires a good foundation of Science knowledge and interest at second level schooling. Students’ performance at second level is found to be the best predictor of performance in higher education (Geiser and Santelices 2007).

The Irish Research Council for Science provides postgraduate and postdoctoral research funding initiatives to students in third level education. Such funding also aids the establishment of nationally and regionally structured PhD programmes. These programmes aim to enhance the education of PhD students, broaden their skill base and in
turn, increase the level of job opportunities available to them. Since 2004, the number of PhD graduates in Ireland has increased significantly. Despite the economic downturn (since 2008) the council is committed to the continual need for investment in PhD education as an underpinning driver of innovation in enterprise especially in the areas of Science and Technology (Department of Enterprise Trade and Employment 2009).

In addition to the teachers and guidance counsellors advising students to study Science at secondary school level, the Government has encouraged Universities and Institutes of Technology to significantly increase the availability of places in undergraduate Science courses (Royal Irish Academy 2009). There is certainly a closer linkage between the values of the curriculum and the market economy in previous years, resulting in the idea that the curriculum should be determined exclusively in terms of what is economically useful (Biesta and Miedema 2002).

2.6.1: Irish Students’ Performance in Science in Comparison to International Standards

As scale studies on misconceptions found that students’ achievement in the senior cycle state examinations wasn’t a good indicator of students’ conceptual understanding of Biology topics (Galvin et al 2015), it was decided to evaluate students performances in science in other tests. The Programme for International Student Assessment (PISA) is an international study carried out by the Organisation for Economic Co-operation and Development (OECD). The main focus is to examine the knowledge and skills of 15 year old students in reading, Mathematics and Science. The most recent published results are from 2012. Ireland has made significant progress in the three areas examined, since 2009 (the last PISA report). In relation to Science, Ireland’s mean score was 522.0, which is
significantly above the corresponding OECD average (501.2). Ireland’s score is ranked 9th among 34 OECD countries and 15th among all 64 participating countries. The mean Science score of students in Ireland has increased significantly since 2006 (508.3) and is also significantly higher than in 2009 (508.0). At both the 10th (lower achievers) and 90th (higher achievers) percentiles, students in Ireland have mean Science scores that are significantly higher than on average across OECD countries (403.9 compared to 379.8 at the 10th percentile, and 636.6 compared to 618.8 at the 90th percentile). The percentage of students below Level 2 (low achievers) in Science in Ireland decreased from 15.5% to 11.1% between 2006 and 2012, while the proportion of higher-achieving students increased from 9.4% to 10.8% (Perkins and Shiel 2014). There is no significant difference between male and female students in Ireland in terms of Science performance. The mean Science scores of both male and female students in Ireland also increased significantly between 2006 and 2012, although the increase was greater among male students than among females. The gender difference has changed slightly from in favour of females in 2006 to in favour of males in 2012 (Perkins and Shiel 2014). However, the performance in state examinations would still be in favour of females over the last five years in relation to Junior Certificate Science and Leaving Certificate Biology (State Examinations Commission 2013).

Nevertheless, 11% of Irish students are still performing below Level 2 (low achievers) on the Science scale, while the proportion of students at or above Level 5 (high achievers) in Ireland is slightly above the corresponding OECD average. Irish students still scored considerably lower than students in China, Finland or Japan who were ranked at the top of the scale. The percentage of students sitting the higher level paper and achieving an honour grade is consistently being maintained at approximately 72% for Science at Junior
and 69.6% for Biology at Senior Cycle (State Examinations Commission 2013). These results indicate that Irish students have a reasonably high level of Scientific knowledge; but compared to countries like China and Finland it is apparent that Irish students are still falling behind (Perkins and Shiel 2014).

PISA bases its assessment on four areas of scientific literacy which includes students’ attitudes to Science, students’ content knowledge, students’ use of Science to identify areas of concern in everyday life and students’ use of Science for explanation and argumentation (Bybee et al 2009). Hurd (1998) suggests a ‘lived curriculum’ incorporating students’ participation in investigative endeavours, problem solving and formulating projects to nurture scientifically literate attributes such as thinking, is necessary to recognise and make use of scientific knowledge for the greater good. O’Neill and Polman (2004) argue that the most productive form of scientific literacy for the individual is that which allows for engagement with and critiquing of scientific research in their everyday lives. The current curricula are too broad in their content cover and do not facilitate any incorporation of the ‘why’s’ and ‘how’s’ of scientific research (O’Neill and Polman 2004).

The Leaving Certificate Examination which focuses on the learning and retention of information (Godsil 2012) contrasts with this type of assessment. This contrast could provide an explanation for students not doing as well in the PISA assessment as they do in the Leaving Certificate Examination. The type of teaching and learning that occurs in Irish schools does not accommodate for multiple types of intelligence, with the exception of Transition Year (Hyland and McCarthy 2009). Transition Year is an optional one year programme that can be taken in the year after the Junior Certificate where students study a
range of different modules and participate in a wide range of extracurricular activities. The exam systems that are in place merely focus on knowledge and the majority of our teaching is preparing the student for these state exams. The interlinking of Science and literacy has received much attention in recent years; however the role of the teacher in the implementation of any new education initiatives should not be overestimated (Pegg et al 2010). Researchers (Baker 2005; Hand et al 2004; Pegg et al 2010; Rivard and Straw 2000) have focused on the possibility, benefits and also the constraint issues raised by the teachers’ involved of teaching for both Science competency and literacy competency simultaneously.

2.7: Summary of key findings

As this study wants to investigate the prevalence of misconceptions and promote conceptual change among senior cycle students, pre-service teachers and service teachers, it was important to identify what are the positives, challenges and constraints in society that causes this type of intervention challenging to implement successfully. Contemporary pedagogical practices in Ireland offer fewer opportunities to develop students’ thinking and argumentation competences (Angell et al 2005). It is evident from the chief examiners report that students struggle on questions where they are required to apply their knowledge to new situations as they are not used to this type of instruction. Students are achieving high grades in State examination with little understanding of concepts. This suggests that there is proficiency in basic factual knowledge in relation to science and that it is this factual knowledge that is for the most part examined in State examinations. The results from the PISA study may have provided a truer understanding of students’ knowledge as students weren’t “taught to the exam” students were required to apply what they had learned. Biology education programs need a multiplicity of pedagogical strategies to
continually interrupt the cycle of misconceptions and to support all teachers and teacher educators to increase the probability of conceptual change and the effective diagnosis, reduction and ultimate elimination of misconceptions (Asay and Orgill 2010; Larkin 2012).

Biology teachers need to engage in continual professional development and reform to develop their subject matter knowledge and pedagogical strategies to eliminate their own misconceptions and assure capacity in eliminating misconceptions from students (Domingos Grilo et al 2012; Johnston 2005). However, many teachers due to the demands of curriculum and time constraints are compelled to seek short cuts and do not pay sufficient attention to students’ misconceptions (Chen et al 2006). Science lessons which elicit debate and argumentation will induce conceptual change through a guided process of cognitive dissonance (Erduran et al 2004; Pine et al 2001; Valanides 2000). Biology needs to intrigue teachers and students and be taught in stimulating, imaginative and creative ways using multiple pedagogical strategies including dialogue and inquiry (Galvin et al 2015). The research evidence indicates that involving external expertise can be crucial for promoting this kind of teacher inquiry and knowledge building (Timperley et al 2008). The contested nature and challenges associated with the new junior Science and senior cycle Biology reform bring the difficulties with development and implementation of reform to light. They are not fully agreed at the moment due to an industrial dispute with the Teacher Unions that has gone on now for over a year, and involved two different Ministers for Education and Skills (Mooney Simmie 2015; Ryan 2015). It is important that teachers feel involved in curriculum implementation (OECD 2005) as they play a significant role in its success or failure (Tamir 2004). In addition, there is certainly a closer link between the values of curriculum and the market economy in recent years,
resulting in the curriculum being determined in terms of what is economically useful (Biesta and Miedema 2002) this was further emphasised by the government increasing the intake of students in third level Science courses.

The literature highlights the need for new and innovative efforts in relation to the continuing education of all teachers (Abell 2008; Luera et al 2005; Sullivan-Watts et al 2013). In order to effectively diagnose deep rooted misconceptions, teachers need inquiry-oriented strategies for a change process (Zhao 2011). By listening to student’s responses, teachers can determine if students’ level of understanding is “deep” or “superficial” (Gooding and Metz 2011; McCarthy and Anderson, 2000; Ozmen 2004). In order for teacher development to have an impact it needs continuous support (Domingos-Grilo et al 2012; Driver et al 2014; Lessing and de Witt 2007).

Increasingly studies showed that teachers need access to broad-based and expansive partnerships in order to build effective capacity to interrogate, justify and change practices (Feiman-Nemser 2003; Mooney Simmie and Lang 2013). The construct of teaching a ‘good enough’ model of teaching, which positions teaching as a complex activity requiring the research base of a clinical practice, the thinking capacities of a dynamic activity taking place within an ever changing social context, and the multilayered developmental supports to assist teachers and teacher educators should all help to enact this successfully (Ruohotie-Lyhty and Moate 2014; Opfer and Pedder 2011). Implementing this new pedagogy of teacher education has its challenges (Vescio et al 2008). Teachers will need continual tutoring supports and conceptual toolkits to develop deep conceptual understanding in their classroom settings (Johnston 2005; Sullivan-Watts
et al. 2013). This ‘good enough’ model of teaching for conceptual change has several implications, requiring policymakers and teacher educators to enact new broad-based conceptual toolkits for teacher education and for all teachers and their students for the classroom of the future. This chapter has provided the scaffolding of the conceptual framework for the literature reviewed in the next chapter.
3.1: Introduction

To date research into how young people acquire accurate higher-order scientific knowledge, and gain an understanding of abstract and challenging concepts through various supports and scaffolds, has occupied much of the science education literature across countries and across continents (Bradley et al 2013). Studies in educational psychology have measured the effect size of a variety of instructional strategies along a continuum, starting with effective instruction and specific task-oriented feedback opportunities (Hattie 2009; Hattie 2012; Hattie and Yates 2014). It appears that within such a clinical model of ‘best practice’ an effective science teacher will merely require technical competence to accurately diagnose the ‘problem’, select and apply appropriate expert knowledge from a bank of available research and display the data indicating successful outcomes. However, as argued by Connell (2009), and other sociologists and philosophers of education (Ball 2003; Biesta 2010) such a clinical ‘best practice’ model fails to take the ever changing dynamic of practice and the socio-cultural context into account and, for the most part, fails in practice to provide reform outcomes demanded by policymakers.

Biology misconceptions have been recognised as a major factor affecting students’ understanding of science at secondary school level with many misconceptions carried onwards to university studies (Coll and Treagust 2003). Studies show that both in-career teachers and pre-service teachers have misconceptions in certain Biology topics (Burgoon et al 2011). Therefore, in order to improve science education, it is imperative that all teachers find new and innovative ways to identify and amend misconceptions that they
may have (Burgoon et al 2011). Effective Science teaching requires the diagnosis and reduction of misconceptions in the teaching of conceptually challenging Biology topics, such as, respiration and photosynthesis. Effective Biology teaching is more appropriately positioned within a ‘good enough’ model of practice operating as a continuous pedagogical cycle of recognition, reduction and removal of misconceptions rather than the application of a singular technique.

In this chapter, a misconception is firstly defined and how misconceptions are formed are identified along with their implications for the teaching of Biology. Secondly, the areas of Biology that prove conceptually difficult are highlighted with emphasis on studies from Ireland, the United Kingdom, Scotland and Turkey. Thirdly, learning is a rather complex phenomenon, the students in the classroom are very different, and each teacher is special concerning strength and limitations of his or her teaching style. Therefore multi-perspective views of teaching and learning are explored as well as ideas of constructivism to help explain how learners develop their understanding of scientific phenomena (Treagust and Duit 2009). Fourth, the wider implications within an international literature as a search for more effective models of Biology teaching and teacher education into the future will be addressed. The final section outlines the prevalent misconceptions in photosynthesis identified in the literature as well as a number of successful intervention programmes that have been carried out internationally. Photosynthesis was the Biological topic chosen to examine as it is a topic that students find conceptually challenging to learn and teachers find difficult to teach. The chapter concludes with the proposed aim of this project’s intervention programme.
3.2: MISCONCEPTIONS

Many different terms to describe Science conceptions were found in the literature, these include; common sense concepts (Halloun and Hestenes 1985), alternative frameworks (Taber 2000), alternative concepts (Gonzalez 1997; Mulford and Robinson 2002), preconceptions (Clement 1982), misunderstandings (Krebs 1999), interpretations that are not scientifically accurate (Bahar 2003), inaccurate prior knowledge (Kendeou and Vanden Broek 2008), naïve or erroneous ideas (Elbert-May et al. 2004) and misconceptions (Brown 1992; Chambers and Andre 1997; Griffiths 1994; Griffiths and Preston 1992; Michael 2002; Schmidt 1997). For the purpose of this project the term ‘misconceptions’ will be used as defined by Crowther and Price (2014) as ‘inaccurate ideas that can predate or emerge from instruction’ and view these as ‘opportunities for cognitive dissonance that students encounter as they progress in their learning’. Particularly in the past decade, evidence would suggest that the problem of misconceptions has become even more acute and the topic consequently has been the subject of considerable exploration internationally (Kambouri 2011). As a consequence, our understanding of the nature of the problem has perhaps improved, although possibly not our understanding of its remediation.

3.2.1: Mistakes versus Misconceptions

Mistakes differ considerably from misconceptions. Mistakes are considered to be errors, blunders or slip-ups made by students because of some oversight. These are easily corrected or revised and typically a student can become aware of the mistake straightforwardly (Hare and Graber 2007). When an incorrect conception is easy for a student to change, it is most likely that it was not a true misconception because misconceptions are deeply held and strongly embedded in the mind of the learner (Hare and Graber 2007). Misconceptions largely differ from mistakes as learners will try to cling
tenaciously to their personal explanation that helps them to understand scientific phenomena (Bransford et al 2002). Misconceptions are resistant to change; whereas mistakes may be acknowledged by the learner.

3.2.2: Oversimplification and Misconceptions

It is common for teachers to simplify complex material, at least when first introducing topics, with the hope that the learning can later be advanced without difficulty. However, this strategy often fails as the initial simplified version and cognitively satisfying conceptualisations form obstacles to the progress of students’ advanced conceptual understanding (Feltovich et al 1993). There is a need at times for teachers to simplify material as a means for students to achieve understanding (Feltovich et al 1993) but the difficulty is when oversimplification of complex conceptual material is used. It appears that there is a natural tendency for human cognitive processing to try and understand material in simpler ways. This may be adequate when the learning material is well structured and well defined. However, it can lead to error and misconception when material is complex (Dember 1991). Simplification strategies, such as teaching topics in isolation from related ones, presenting only clear instances (without mentioning the exceptions to the rule), and requiring only recall assessment (the lowest level of knowledge according to Blooms Taxonomy) are often in conflict with the realities of advanced conceptual understanding. Where components of knowledge are interrelated, where context-dependant exceptions are evident and where the ability to respond flexibly to application, synthesis and comprehension situations is required (Feltovich et al 1993). When introductory material is oversimplified it can interfere with successful advanced learning resulting in a powerful potion for misconception (Coulson et al 1989). The quantity of material in the Biology syllabus lends to a fast pace to ensure all the material is
covered. Therefore, there are considerable pressures placed on both teachers and students to move through the material quickly and simplification in both assessment and instruction may be part of a ‘survival strategy’. There is no doubt that a curriculum stance that values “coverage” is prevalent in Ireland (Hennessy et al 2011).

3.2.3: Implications Misconceptions have on the Learner

Misconceptions can be very stable and reluctant to change and are not easily discarded; for many, the misconceptions can continue to emerge both before and after instruction takes place (Khalid 2003; Smith et al 1994; Yenilmez and Tekkaya 2006). The students’ ability to learn new scientific information depends greatly on the students pre-existing beliefs and these play a significant role in the development of the student’s learning (BouJaoude 1991). It is this knowledge that determines what new knowledge they can construct and retain, therefore what they already know about a topic will either enhance or hinder their learning (Sewell 2002). Unless presented, information is stored in the long term memory it will be quickly forgotten (Snowman and Biehler 2006). Meaningful learning, which occurs when new information can be related to existing knowledge, is much more resistant to forgetting than is rote memorisation. Thus, using demonstrations, analogies, concept maps, explanations and imagery can help increase the chances for meaningful learning to occur (Morrison et al 2011). It is imperative to realise how important the information already stored in the long term memory is to the learner. This is one of the most important factors influencing learning (Angell et al 2005). If students have stored incorrect information in the long term memory it makes learning new material very challenging as the long term memory has a major effect on the learning of new ideas and concepts. Misconceptions stored in the long term memory can have a serious effect on the future learning of different concepts. The longer a misconception is left unchallenged, the more
likely the misconception is to remain in the student’s brain (Gooding and Metz 2011). If the student’s ideas are not tackled during early instruction, the misconceptions can remain throughout the student’s school life. As many secondary school students don’t receive Science training beyond lower secondary education (Odom and Barrow 1993), some can even retain the misconceptions right through to adulthood and for the rest of their lives (Driver et al 1994; Keeley et al 2005).

3.2.4: Formation of Misconceptions

Throughout our lives we are immersed with information. The process of understanding this information can lead to the formation of our misconceptions. Learning Science is a cumulative process and each new piece of information is added to what students already know about the topic at hand. Research has shown that children as young as three years old bring to lessons a lot of misconceptions about scientific phenomena that can interfere with students’ learning of correct scientific concepts (Driver and Easley 1978; Fleer 1999; Palmer 2003; Smolleck and Hershberger 2011; Taber 2000). There are a number of sources that contribute to misconceptions. Misconceptions can result due to the number of contacts students make with the physical and social world around them, they may occur due to something the student experienced in their personal life, from communication with different teachers and friends or through sources of media (Gilbert et al 1982; Gilbert and Zylberstajn 1985; Griffiths and Preston 1992). The particular knowledge that is constructed by an individual will be affected by the learner’s prior knowledge and experience and the social context in which learning takes place (Grayson et al 2001; Von Glasersfeld 1992). These misconceptions formed by students can be quite resistant to change at times. The teaching strategies, the textbooks, curriculum designs (Stern and Roseman 2004) and more importantly the teachers’ subject matter knowledge and
pedagogical content knowledge are also possible contributing factors towards students’ formation of misconceptions. Other factors include the teacher’s knowledge of students’ understanding and learning, knowledge of curriculum, knowledge of instructional strategies, knowledge of assessment and the orientation to teaching subject matter (Stern and Roseman 2004).

3.2.5: Teachers and Parents Contribution to the Formation of Misconceptions

Adults play an imperative role in creating misconceptions in students; both parents and teachers pass on inaccurate information to the students which may lead to misunderstanding and confusion in further topics (Donovan and Bransford 2005; Gooding and Metz 2011; Soyibo 1995). Teachers who are less competent in subject-matter knowledge may propagate incomplete or erroneous views to their students through inaccurate teaching or uncritical use of textbooks (Sanders 1993). Many of the studies reviewed, reported a direct link with teachers and the formation of students’ misconceptions (Barrass 1984; Dikmenli 2010; Donovan and Bransford 2005; Flores et al 2003; Hashweh 1987; Kose 2008; Sanders 1993; Soyibo 1995; Yip 1998a; Yip 2001). For example, Yip (1998a) carried out research to investigate the presence of misconceptions amongst practicing Biology teachers in Hong Kong. Findings from the study revealed that 50% of practicing Biology teachers hold misconceptions in a number of basic biological concepts that are required in the upper secondary Biology curriculum. This is a major cause of concern for Biology education as many of these misconceptions are also detected in upper secondary school students; therefore it is highly probable that teachers may have served as a direct agent for propagating and reinforcing the incorrect views to their students. The problem is even more worrying when it is found that experienced teachers demonstrate similar conceptual problems (Barrass 1984; Hashweh 1987; Sanders 1993;
Soyibo 1995). Teachers at the primary and secondary education levels and the lecturers at the university assume very important roles regarding the identification of their own misconceptions and the employment of alternative teaching strategies to eliminate or at least minimise the misconceptions of their students.

Dikmenli (2010) carried out a study to investigate pre-service teachers’ misconceptions of cell division. Pre-service teachers’ understanding of mitosis and meiosis was examined by two different methods, drawings and interviews. On analysis of the drawings and interviews pre-service Biology teachers were found to have significant misconceptions regarding cell division. 46% of the participants produced drawings with misconceptions related to mitosis while 54% produced drawings with misconceptions related to meiosis. Yip (1998b) carried out a study on secondary school Biology teachers to determine their misconceptions of the circulatory system. The observations reported that a large proportion of practicing teachers hold the same misconceptions about the circulatory system as their students. Similarly, Soyibo (1995) looked at different misconceptions commonly encountered in the written work of students and discovered that most of the misconceptions were found to be perpetuated by teachers of Biology including the authors of some school Biology textbooks. A study conducted by Bursal (2012) found that at least 40% of the pre-service teachers examined from an American university study possessed 7 out of the 11 misconceptions assessed including “plants get their food from the soil”. These studies lends support to the view and cautions that teachers can be a direct and major factor in propagating and perpetuating students’ misconceptions in Science learning.
3.2.6: Teachers’ Underestimation of the Existence of Misconceptions

There is certainly an assumption that secondary school teachers have adequate subject matter knowledge and are competent in translating their knowledge into curriculum materials for instruction in the classroom, but for many this is not the case (Mak et al 1999). Even the teachers that are aware of misconceptions don’t understand how misconceptions develop or fully appreciate their impact on their instruction (Mak et al 1999). In addition, Hunt and Minstrell (1998) stated that children’s difficulties in Science occur because students’ conceptions before teaching are not taken into account and therefore communication barriers between teachers and learners cannot be overcome. Teachers at this level underestimate the existence of misconceptions and don’t use any specific teaching strategies to establish any perceived notions held by students, other than general experimentation (Burgoon et al 2011). On the other hand, teachers can sometimes think that by sharing the correct ideas with the students they will automatically make students think otherwise (McComas 2005). Ideas cannot be forced upon students when they are not ready to accept them as valid information. Students should be provided with adequate time for investigation and processing as well as opportunities to make connections to everyday life. Students should be taught to change their minds not fill their minds (McComas 2005). Most service teachers are aware of misconceptions but they find it challenging or are reluctant to help students (Gomez-Zwiep 2008). Recognising what misconceptions students hold is an essential component in effectively teaching Science. A study by Gomez-Zwiep (2008) investigated what teachers know about student Science misconceptions and how they address student misconceptions in instruction. The results from the study suggested that a significant number of the teachers interviewed were of the belief that students entering primary education have “blank slates” and that they enter the classroom possessing no previous Science conceptions (Sewell 2002). Pre-service teachers
have limited understanding of students’ prior knowledge and are unaware of students’ conceptual difficulties (Kapyla et al 2009).

3.2.7: Textbooks and Misconceptions

Studies also highlighted that textbooks are another prevalent source that contributes to the formation of misconceptions by students due to incorrect, outdated or misleading information and representations (Dikmenli and Cardak 2004; Dikmenli 2010). These textbooks lack clarity on important concepts allowing students to continue to have confidence in existing misconceptions (Kendeou and Van den Broek 2008). Designs of textbooks haven’t considered the students’ prior knowledge; they lack representations to clarify abstract ideas as well as questions to challenge students’ common misconceptions (Stern and Roseman 2004). Science teachers need to be aware of misconceptions in the teaching literature (Carter 2004). Textbooks are usually regarded by educators as a good source of information for teaching students (Abimbola and Baba 1996). However, Science textbooks are continuing to espouse incorrect, outdated and misleading views (Gibson 1996). Storey (1990) has undertaken a series of investigations in relation to the presence of misconceptions in Biology textbooks (Storey 1989; 1990; 1991). He found that the Biology chapters that held the most misconceptions were in relation to cells, metabolism, molecular Biology, diffusion and osmosis, physiology and plant growth. However, some of the misconceptions associated with cells for example could be due to the material in the textbooks being outdated rather than textbook misconceptions or errors as it is extremely difficult for even active researchers in the area of cells to stay current with such scientific knowledge (Storey 1990).

Textbooks have stated that the plant cell walls are composed of only cellulose but in reality they consist of only 9-25% cellulose, 10-35% pectin polysaccharides, 20-50%
hemicelluloses, 10% proteins and lignin (Storey 1990). This could be an error of knowledge or oversimplifications on the authors’ behalf and not a misconception held, however, this text could lead to the formation of misconceptions among many if not addressed. A number of misconceptions have been highlighted in textbooks relating specifically to Photosynthesis. Firstly, the Photosynthesis equation; drawing a single arrow wrongly implies that Photosynthesis occurs in one step. Many small arrows should be used instead, to emphasise that Photosynthesis occurs in a series of steps (Hershey 2004).

Textbooks state that all plants are photosynthetic. Although they constitute less than 1% of plant species, a few hundred parasitic species lack chlorophyll and are therefore not photosynthetic (Hershey 1999). While it is so commonly stated in textbooks, glucose is not the major photosynthetic product produced. There is virtually no free glucose produced in Photosynthesis (Storey 1989). The most common product is starch or sucrose.

In relation to the different stages of Photosynthesis; textbooks have insinuated that the dark reactions in Photosynthesis occur only during the night (Storey 1989). Finally, the *Elodea* plant which is generally used to demonstrate the effect of light intensity on Photosynthesis is thought to produce pure oxygen gas, however as photosynthetic oxygen dissolves, some of the nitrogen comes out of the solution therefore the gas produced is not pure oxygen. The Biology textbooks contain hundreds of misconceptions which have not received enough attention to prevent their negative impacts. These misconceptions can potentially mislead thousands of teachers and students (Hershey 2004).

As highlighted above, oversimplification contributes to misconceptions; an example of oversimplification in the textbook leading to misconceptions is defining osmosis as the movement of water across a semi-permeable membrane. A more scientifically acceptable definition for osmosis is the movement of water molecules from an area of higher water
concentration to an area of lower water concentration through a selectively permeable membrane. Another example of oversimplification in the textbook; is stating the xylem brings large quantities of water from the roots to the leaves. The correct scientific concept is the xylem is a vascular tissue that conducts water and dissolved minerals from the roots to other parts of the plant along with providing it with mechanical support. It is not water alone that is conducted from the roots and it is not just to the leaves that the materials go (Abimbola and Baba 1996).

Abimbola and Baba (1996) carried out an extensive study on the misconceptions in a Science teachers association of Nigeria (STAN) upper secondary school Biology textbook. The book was examined page-by-page in search of misconceptions. Once the misconceptions were identified, three Senior lecturers in Biology and education validated the identified misconceptions along with the suggested alternatives. A total of 115 misconceptions remained after validation. The book chapters that held the highest percentage of misconceptions were; Nutrition, Respiration, Co-ordination and Reproduction. The main categories of misconceptions identified in the study were in terms of words representing concepts that are wrong, for example, the use of the term “warm blooded” and statements that are wrong for example “predation is the act of consuming another organism”.

These studies have illustrated that textbooks are a common source that contributes to the formation of misconceptions among students. Textbooks are the dominant resource for the Science instruction in most classrooms, therefore text-based methods of facilitating conceptual change need to be examined (Angell et al 2005).
3.2.7.1: Diagrams and Images in Textbooks

It is not alone the text in the Biology textbooks that have lead to the development of misconceptions. The use of diagrams, analogies and representations within textbooks has also been found to often reinforce or induce students naive misconceptions as they lack the necessary explanations for these analogies and diagrams (Güler and Yağbsan 2008; Stern and Roseman 2004). For example, contrary to textbook life cycle diagrams, fruits sometimes develop without pollination and fertilisation which are termed parthenocarpy. Such seedless fruits include bananas and pineapples (Hershey 2004). Textbooks can also present pathways and cycles as diagrams of the intermediates; glycolysis from glucose to pyruvate, or the Krebs cycle with citrate and oxaloacetate. However, the enzymes involved in the formation of the intermediates and products are often left out of the diagram (Storey 1990). Textbooks contain images of the chloroplast as being shaped like an American football, whereas in fact they can vary in shape. Chloroplasts may be spherical, discoid, elongated, or lobed. In textbooks the entire chloroplast is coloured green; a more accurate sketch would show the green chlorophyll only in the thylakoids inside the chloroplasts (Storey 1990).

3.2.7.2: Examination of Senior Cycle Biology Textbooks

In this study, four Senior Cycle Biology textbooks were examined along with 2 revision textbooks. There has been a significant increase in the sale of revision books like ‘Revise wise’, ‘Rapid revision’, ‘Essential exam revision’ and ‘Less stress more success’ (The Irish Times 2011) therefore it is imperative that these are analysed too as students rely heavily on them for revision. One of the most popular senior cycle Biology textbooks used in Ireland is ‘Leaving Certificate Biology’ (O’Callaghan 2005). Three other senior cycle Biology textbooks used in Ireland are ‘New Senior Biology’ (Scott and Maume 2005),
‘Discovering Biology’ (Meaney 2005) and ‘Leaving Certificate Modern Biology’ (Reville 2004). The revision textbooks that were analysed were ‘Revise wise’ (O’Callaghan 2006) and ‘Essential Exam Revision’ (Dilleen 2007). The following oversimplifications and inaccurate information that could cause the development of misconceptions were found in the above textbooks when examined.

Table 3.1 The text and representations found in the Senior cycle Biology textbooks and revision books that could contribute to the formation of misconceptions among students and teachers are presented, along with the author and page number of the book that was examined. The ‘most correct’ scientific concept is also provided.

<table>
<thead>
<tr>
<th>‘Most correct’ scientific concept</th>
<th>Text/representation that could contribute to the formation of misconceptions</th>
<th>Author</th>
<th>Page no.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photosynthesis should be represented with more than a single arrow as there are a number of steps involved.</td>
<td>The Photosynthesis equation is represented using a single arrow implying that it occurs in one step, also light is written on the left of the equation with chlorophyll above the arrow (appendix 17a).</td>
<td>(O’Callaghan 2005) (Dilleen 2007) (O’Callaghan 2006) (Meaney 2005) (Reville 2004) (Scott and Maume 2005)</td>
<td>19, 105, 32, 56, 122, 126, 112</td>
</tr>
<tr>
<td>Although they only represent 1% of the plant species, not all plants Photosynthesise.</td>
<td>All plants carry out Photosynthesis and are therefore producers. All plants are producers.</td>
<td>(O’Callaghan 2005) (Meaney 2005)</td>
<td>29, 232</td>
</tr>
<tr>
<td>Photosynthesis is not part of carbon cycle but carbon dioxide is needed for the process of Photosynthesis.</td>
<td>The book states it is important that the carbon dioxide is replaced in the atmosphere so Photosynthesis can continue. This statement can lead to students thinking that Photosynthesis is part of the carbon cycle. The book insinuates that Photosynthesis and respiration are processes in the carbon cycle. As under the heading for carbon cycle the textbook states that plants remove carbon from the</td>
<td>(O’Callaghan 2005) (O’Callaghan 2006) (Dilleen 2007)</td>
<td>32, 18, 14</td>
</tr>
</tbody>
</table>
environment in Photosynthesis and return it in respiration.

<p>| Plant cell walls consist of only 9-25% cellulose, 10-35% pectin polysaccharides, 20-50% hemicelluloses and 10% proteins | Plant cells are enclosed by a rigid cell wall made of cellulose. The plant cell wall is made of cellulose. The plant cell wall is made of tightly woven cellulose fibres. | (O'Callaghan 2005) | 76, 80 |
| It is only the thylakoid layer of the chloroplast that is green in colour. | In the textbook the chloroplasts are coloured green (appendix 17b). It also states that chloroplasts are green structures in plants which Photosynthesis takes place. Chloroplasts are the round dark green structures. Chloroplasts are green. Chloroplasts are little green machines that make food for plants. | (O'Callaghan 2005) | 76 |
| Sunlight energy is harnessed. | Light is absorbed. Photosynthesis absorbs light. | (O'Callaghan 2005) | 105 |
| It is not pure oxygen gas produced, nitrogen is also produced. | In the experiment to demonstrate the effect of light intensity/carbon dioxide concentration on Photosynthesis an arrow points to the pure gas produced (appendix 17c) The gas produced is labelled oxygen (appendix 17d) | (O'Callaghan 2005) | 112 |
| This process is projected as being a one stage process when in fact it can occur in one or two stages. | Enzymes convert glucose to energy (ATP) (appendix 17e). | (O’Callaghan 2005) | 114 |
| A selectively permeable membrane or differentially permeable membrane would be the preferred terms to use. | Semi-permeable membrane was stated in the textbook which could be wrongly construed as partially permeable or partially impermeable. It states that the cell membrane is semi-permeable. Osmosis is the movement of water molecules across a semi-permeable membrane. | (O'Callaghan 2005) | 39, 84, 126 |
| Vascular tissues are found in more parts of the plant than just the leaf. | Vascular tissues xylem and phloem are found in the leaves of plants. | (O’Callaghan 2005) | 233 |
| Any part of the plant | The function of the leaf is to carry out | (O'Callaghan 2005) | 233 |
| <strong>that contains chloroplasts which has the pigment chlorophyll can carry out Photosynthesis.</strong> | Photosynthesis. | (Meaney 2005) | 122 |
| Diffusion is the movement of molecules | Diffusion is the spreading of molecules… Diffusion is the spreading out of the particles of a substance from an area of its higher concentration into regions of its lower concentration. | (O’Callaghan 2005) | (Reville 2004) | 247 85 |
| In order for Photosynthesis to occur chlorophyll must be present along with sunlight, carbon dioxide and water. | Most autotrophs are green plants they make their food using carbon dioxide, water and sunlight as a form of energy. Chlorophyll converts the light into glucose. | (O’Callaghan 2005) | (Dilleen 2007) | 275 33 |
| Cross-pollination involves the transfer of pollen grains from the anther to the stigma of a different plant but of the same species. | Cross pollination is the transfer of pollen grains from the anther of one plant to the stigma of another plant. The statement implies that the pollen grains from any flower may pollinate the flower of another plant whether or not they are the same species. Cross pollination means that the anther and carpel are on different plants. This leads to cross-fertilisation, which produces stronger and healthier offspring. Cross pollination is where pollen reaches the stigma of a flower on a different plant of the same species. | (Dilleen 2007) | (Reville 2004) | (O’ Callaghan 2006) | (Meaney 2005) | 89 387 228 54 |
| Under the light microscope students won’t be able to identify organelles like mitochondria and chloroplasts. | Images shown of animal and plant cells as seen under the light microscope are misleading (appendix 17f). | (Dilleen 2007) | (Meaney 2005) | (Reville 2004) | 149, 150 75,78 |
| Results need to be analysed before a conclusion is made to reject, repeat or accept the results of the experiment. | Diagrammatic representation of the scientific method without the results included. | (O' Callaghan 2006) | | 2 |
| Anabolic reactions form larger molecules from smaller ones, energy is required. Catabolic reactions break down larger molecules to form smaller ones. | Anabolic reactions form larger molecules from smaller ones. Catabolic reactions break down larger molecules to form smaller ones. | (O' Callaghan 2006) | | 11 |</p>
<table>
<thead>
<tr>
<th>smaller ones and energy is released.</th>
<th>Love heart image used when describing the heart.</th>
<th>(O'Callaghan 2006) 152, 153</th>
</tr>
</thead>
<tbody>
<tr>
<td>A human heart is not shaped in a love heart.</td>
<td>The function of the xylem is to transport water.</td>
<td>(O'Callaghan 2006) 42</td>
</tr>
<tr>
<td>The xylem is a vascular tissue that conducts water and dissolved minerals from the roots to other parts of the plant along with providing it with mechanical support.</td>
<td>The diagram of the heart labels only two semi lunar valves leading to students thinking that there are only two semi-lunar valves (appendix 17g). Only two semi-lunar valves are labelled (appendix 17h)</td>
<td>(O’Callaghan 2005) 261</td>
</tr>
<tr>
<td>The heart has in fact three semi-lunar valves.</td>
<td>Diagnoses of the breathing system and the digestive system lead students to believe that the trachea and the oesophagus are the same thing.</td>
<td>(O’Callaghan 2005) 274 290</td>
</tr>
<tr>
<td>Students may not realise that the arrow means that the organism preys on the next organism on the food chain.</td>
<td>The meaning of arrows in food chains as “eats”</td>
<td>(O’Callaghan 2005) 30 34</td>
</tr>
<tr>
<td>Predation is one of such interactions that exist between two organisms and it involves hunting, capture, and killing of prey by the predator, not just the consumption of prey.</td>
<td>Predation occurs when one organism kills another organism to obtain food. Predation is the act of one organism killing another organism for food. Predation is the killing of one animal by another for food.</td>
<td>(Scott and Maume 2005) 35 (Meaney 2005) 44 (Reville 2004) 42</td>
</tr>
<tr>
<td>Phloem transports organic compounds and other nutrients like potassium from the leaf to different parts of the plant.</td>
<td>Phloem carries only sugars. Phloem transports only food.</td>
<td>(Meaney 2005) 205 (Reville 2004) 230</td>
</tr>
<tr>
<td>Photosynthesis is a process in which light energy is used to produce sugar and</td>
<td>Photosynthesis is the manufacture of sugar in a plant using sunlight energy.</td>
<td>(Meaney 2005) 122</td>
</tr>
</tbody>
</table>
Interphase is not a short stage in the cell cycle. Misleading diagram of the cell cycle, interphase stage portrayed as short stage. (Reville 2004)

Textbooks are the dominant resource for the Science instruction in most classrooms, therefore text-based methods of facilitating conceptual change need to be examined (Kendeou and van den Broek 2008).

3.2.8: Methods that can be used by Educators to Identify Students’ Misconceptions

There are several ways of obtaining information about students’ and teachers’ conceptual understanding. Individual interviews (Ahopelto et al 2011; Brown and Schwartz 2009; Kapyla et al 2009; Keles and Kefeli 2010; Lin 2004; Parker et al 2012; Partosa et al 2013), open-ended questions (Akpinar 2007; Deshmukh 2012; Ozay and Oztas 2003; Parker et al 2012), prediction-observation-explanation (Brown and Schwartz 2009; Domingos-Grilo et al 2012), multiple choice questioning (Akpinar 2007; Balci et al 2006; Cakiroglu and Boone 2002; Krall et al 2009; Parker et al 2012), two-tier diagnostic tests (Lin 2004; Partosa et al 2013; Svandova 2013; Yenilmez and Tekkaya 2006), concept mapping (Ahopelto et al 2011; Lin and Hu 2003), drawings (Kose 2008), role play (Ross et al 2010), models (Ross et al 2010), close ended questionnaires (Boomer and Latham 2011; Marmaroti and Galanopoulou 2006; Yip 2007), conceptual change texts (Mikkila-Erdmann 2001) and concept cartoons (Ekici et al 2007) may effectively elicit students’ and teachers’ in-depth thinking but it is important to be aware that some methods are more difficult than others to quantify and are sometimes subjective.

Kose (2008) investigated the effect of the drawing method in combination with interviews on determining university students’ misconceptions. Forty three misconceptions were determined from the students’ drawings about Photosynthesis and Respiration in plants.
Misconceptions identified in the drawings overlapped in the interviews carried out. The study concluded that drawings can provide valuable information for teaching and learning in determining misconceptions and more importantly they provide an open-ended means for creative expression that is difficult to achieve with other assessment strategies.

For research to assist the teacher in identifying misconceptions it is necessary to develop methodologies which can be readily used by teachers in their classroom environments. Of these many approaches, interviews, and multiple-choice diagnostic tests are the most common methodologies and have acquired strong support as a viable approach (Abdullah and Scaife 1997; Adeniyi 1985; Dikmenli 2010; Osborne and Gilbert 1980; Peterson et al 1989; Schmidt 1997). According to Schönborn and Anderson (2010) conventional multiple-choice tests do not adequately assess student understanding. Although multiple-choice tests have been used to evaluate students’ content knowledge, they have some limitations with determining students’ reasoning behind their choices. However, many teachers agree that one of the best ways to measure student understanding is to assess how well they can explain a concept to someone else (Teichert and Stacy 2002). Therefore, multiple-choice questions can be validated by asking students to give reasons for their answers. In addition, two-tier multiple-choice items appear to provide a feasible approach for evaluating students’ understanding, and for identifying commonly held misconceptions (Haslam and Treagust 1987; Odom and Barrow 2006; Peterson et al 1989). The items in two-tier multiple-choice diagnostic instruments are specifically designed to identify students’ misconceptions and misunderstandings in a limited content area. The first part of each item consists of a multiple-choice content question having two, three or four choices. The second part of each item contains possible reasons for the answer to the first part. Incorrect reasons are derived from actual students misconceptions gathered from literature
and interviews, (Tan et al 2002). This type of test is more readily administered and scored than the other methods, and are useful for classroom teachers (Tan and Treagust 1999). On the other hand, objectively scored two-tier tests also have the disadvantage of detecting far fewer conceptions than students may actually possess within a content domain. By contrast, open-ended two-tier tests allow teachers to explore each student’s reasoning patterns and supporting conceptions (Voska and Heikkinen 2000). Most reported strategies involve a combination of multiple-choice tests, interviews, or other tasks.

3.2.9: Overcoming and Eliminating Misconceptions

In order to address misconceptions, teachers firstly need to understand how students’ misconceptions are formed and where they come from (Gooding and Metz 2011). As teacher educators, service teachers and pre-service teachers have a significant influence on the student’s knowledge and understanding, this increases the chances of the misconceptions the teachers and pre-service teachers hold to be embedded in the students they teach (Sanders 1993). Teachers will need to establish and confront their own misconceptions before they can assist the students with theirs (Burgoon et al 2011). It is the teacher’s responsibility to use appropriate and effective instructional strategies when addressing misconceptions. In order for teachers to implement conceptual change strategies amongst their students, they need to possess a very high standard in their content knowledge and a high degree of awareness of student’s misconceptions (Diakidoy and Iordanou 2003; Gomez-Zwiep 2008). Teachers, who are less knowledgeable, are more likely to rely upon low-level questions and to give their students less opportunity to speak (Valanides 2000). According to Bergquist and Heikkinen (1990), it is critical to provide students with opportunities to verbalise their ideas to promote concept building and remediate misconceptions. By simply listening to student’s responses and explanations,
one can determine if the students’ level of understanding is “deep” or “superficial” (Gooding and Metz 2011). Only then will deep–seated misunderstandings be identified, overcome and eliminated (Özmen 2004).

Misconceptions will not be resolved by teachers telling the students they are incorrect and simply providing them with the correct scientific answer (Taber 2000). If such misconceptions are evident, a teacher can help the student, but it is up to the learner themselves to correct the misconception (Modell et al 2005). Instruction should confront misconceptions; teachers should try to set up experiences through demonstrations and group activities for their students where their pre-conceptions are challenged. Discussions play a vital role in overcoming misconceptions, as students are unlikely to change their belief if they are just told that their idea is wrong (Taber 2000). The teacher could provide the students with opportunities to link other concepts with the concept being taught to demonstrate the advantages of expert knowledge to their pre-existing beliefs. In order to overcome their misconception, the student is required to permanently eliminate their misconception by replacing the misconception with an expert scientific concept (Smith et al 1994). This is an area that challenges many students and teachers.

Studies have identified that textbooks are a prominent source that contributes to the formation of misconceptions by students (Abimbola and Baba 1996; Dikmenli and Cardak 2004; Gibson 1996; Hershey 2004; Storey 1990). As suggested by Abimbola and Baba (1996) teachers should thoroughly read through the short listed Biology books and choose the one with the least number of misconceptions. However, for many schools it is the Principal who selects the textbook not the teacher, who may not be a subject specialist in the area (Van Steenbrugge et al 2012). Therefore teachers may not be given the
opportunity to select the book of their choice or get the chance to even analyse the different books on offer. Once a textbook is selected, misconceptions identified should be brought immediately to the attention of students at the beginning of classes. This process should be reinforced each time the affected topics are taught. Teachers should discuss misconceptions with their students because telling them alone does not guarantee that they would correct themselves. If teachers were educated to use textbooks more critically and selectively, they would be alert to the inaccurate information described in textbooks (Yip 1998a).

Researchers have found that using good analogies can help students overcome misconceptions as the analogy can assist them in changing the conceptual model they use to think about a scientific phenomenon (Clement and Brown 2004). Similarly, making students create concept maps in which they are constructing a correct framework for new knowledge has been successful in overcoming misconceptions in Science, particularly if the exercise is carried out in small groups (Cullen 1990). The underlying technique involved is tying new knowledge to relevant concepts and propositions already possessed (Austin and Shone 1995). The maps provide a representation of knowledge and hence can be used to infer accuracy and depth of knowledge. Concept mapping provides an opportunity for students to think deeper about the scientific concept and help them to link one concept with another related concept (Austin and Shone 1995; Briscoe and LaMaster 1991; Broggy and McClelland 2008; Cassata et al 2004; Horton et al 1993; Ruiz-Primo and Shavelson 1996; Stoddart 2006). For a teacher, concept maps are a discrete way of identifying what each individual student finds challenging and also the areas that cause common confusion within a classroom (Kern and Crippen 2008). Over the last ten years research has been carried out on using digital storytelling (McLellan 2007; Wilson 2002)
conceptual change text accompanied by animation (Akamca et al. 2009; Çepni et al. 2006; Ekici et al. 2007; Keogh et al. 1998; Naylor and Keogh 1999; Saka 2006; Stephenson and Warwick 2002) and computer games (Kara and Yesilyurt 2008) to assist in the classroom to overcome and eliminate students’ misconceptions. Such teaching-learning activities have proven to reduce many misconceptions for students and for some, dismiss them completely (Karamustafaoglu et al. 2003). Researchers argue that student achievement increases significantly with the use of computers in Science education (Chang and Chang 2001; Coye and Stonebraker 1994; Powell et al. 2003; Rowe and Gregor 1999; Tjaden and Martin 1995; Tsai and Chou 2002). In addition, it is reported that student abilities and skills in scientific investigations are affected positively by computer assisted instruction (Bayraktar 2000). Schneps et al. (2013) found that using a solar walk app on the Apple iPad with brief exposures to simulations of the solar system reversed a number of tenacious misconceptions amongst students of astronomy.

Both Science reflective journal writing and refutation text are seen to be the most effective text based means of overcoming misconceptions. Science reflective journal writing is when students reflect on an experiment or a particular topic covered in class, the teacher examines the journals and addresses the questions that arise at the end of the week (Towndrow 2008). Researchers have found that it dramatically increases students’ conceptual understanding and is a useful tool in identifying and overcoming misconceptions (Hohenshell and Hand 2006; Moon 2006; Towndrow 2008). Refutation text is a text structure that includes elements of argumentation. Research indicates that reading refutation text rather than traditional text is more likely to result in conceptual change (Tippett 2010) as traditional text doesn’t create the necessary cognitive conflict needed to generate dissatisfaction with a misconception (Kendeou and van den Broek
Refutation text allows the student to become aware of their misconception and allows them to change their thinking. Research into the development of refutation text has been carried out successfully in a number of countries such as Australia (Palmer 2003), Finland (Mikkilä-Erdmann 2001) and Canada (Kendeou and van den Broek 2007). Refutation text challenges readers’ misconceptions (Tippett 2010). It consists of two components: the statement of a commonly held misconception, and an explicit refutation of that misconception with an emphasis on the scientific explanation (Guzzetti 2000). Refutation text explicitly states a misconception and then refutes it, readers who hold that misconception are more likely to recognise that their prior knowledge is incorrect or inadequate (Guzzetti et al. 1993). Text alone, is not enough to facilitate conceptual change for all students as some students understand and comprehend information through imagery (Tippett 2010). In addition, students with ineffective reading strategies would also require more assistance (Guzzetti 2000). Therefore, refutation text used in conjunction with other types of text, with videos, demonstrations, hands-on experiments, and other activities, will increase the likelihood of conceptual change. Educators should also be aware of the power of refutation text, so that they will choose books that incorporate refutation text, and perhaps even develop their own instruction utilising the refutation text structure (Tippett 2010). Alparslan et al. (2003) used conceptual change texts in order to test the effectiveness of conceptual change strategies for eliminating misconceptions. In these texts, misconceptions are identified so that students are made aware of them and examples are given to help activate those misconceptions. The students are then presented with evidence that their current understanding is incorrect in order to promote dissatisfaction with their misconceptions. Giving the students the opportunity to practise using the correct scientific explanations helps them to eliminate the existing misconception and develop a new, scientifically accurate conception.
There is a still large gap in the research concerning what techniques are most effective at improving teachers’ ability to address their students’ misconceptions once they are identified. This issue requires further attention during teacher education and professional development for pre-service teachers. Research suggests that at present, teachers are not prepared to confront Science misconceptions when they arise, even if the teachers have identified them and recognised the need to change them (Gomez-Zwiep 2008; Halim and Meerah 2002; Meyer 2004).

3.3: Research into Identifying Areas of Difficulty in Biology

From the research to date, it is evident that Irish secondary school students, third level students and teachers alike find some areas of Biology very difficult. It has also been noted that they hold a number of misconceptions in these difficult areas (Galvin and O’Grady 2012). It is essential to overcome these misconceptions in order to increase the standard of Biology among both secondary and third level students. It is also of major importance that anyone teaching Biology is aware of the areas of difficulties for the students. It is crucial that Biology teachers are conscious of the misconceptions that their students could possibly hold to assist in overcoming them (McLaughlin 1992). This section looks at research that has been carried out nationally and internationally in identifying the prevalent Biology topics that students find difficult to understand. Five studies will be discussed; one from Scotland (Bahar et al 1999) two from Turkey (Cimer 2011; Tekkaya et al 2001), the British Examiners’ report for 2010 (University of Cambridge International Examinations 2010) and the Chief Examiners’ reports on students’ performances in the senior cycle Biology examination for the years 2001, 2002, 2004, 2009 and 2013.
3.3.1: Identifying Difficult Topics in Biology- An Investigation from Scotland

Bahar et al (1999) carried out a survey on first year students studying Biology in the University of Glasgow. Students were asked to prioritise Biology concepts within the syllabus that they found difficult. The teachers’ opinions of the topics were also looked at. In this particular study students were given a questionnaire, which contained all the Biology topics on the syllabus. The students were asked to describe the Biology topics using easy, moderate, difficult or didn’t study topic. The topics that students found difficult are shown in Table 3.2.

Table 3.2 List of Biology topics that Scottish students found difficult to understand and learn

<table>
<thead>
<tr>
<th>Topics Identified by the students as being difficult</th>
<th>% of pupils that identified topic as being difficult</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monohybrid and di-hybrid crosses and linkages</td>
<td>22.2%</td>
</tr>
<tr>
<td>Genetic engineering</td>
<td>13.4%</td>
</tr>
<tr>
<td>Genetic control of development and metabolic processes</td>
<td>13.3%</td>
</tr>
<tr>
<td>Meiosis</td>
<td>11.9%</td>
</tr>
<tr>
<td>Central nervous system, sense organs and co-ordination</td>
<td>10.8%</td>
</tr>
<tr>
<td>Gametes, alleles and genes</td>
<td>10.4%</td>
</tr>
</tbody>
</table>

With the exception of the Nervous system topic, the remainder of the topics are somewhat linked to Genetics so one could conclude that students find it difficult to understand Genetics and the concepts involved. In relation to the teachers, they too indicated that one of the most difficult topics to teach are Monohybrid and Di-hybrid crosses (Bahar et al 1999). One to one interviews were carried out with the students to find out possible reasons for difficulty in this particular area. It was noted that the language in Genetics can be very complex and there is a large vocabulary of words such as alleles, genes, and chromosomes that one has to distinguish between. In relation to Meiosis and Mitosis,
students found the topics difficult as they were very similar. Both students and teachers believed that not enough time is allocated on the syllabus to unfold and tackle this difficult area. Teachers and students needed more time for discussing the different concepts and carrying out example exercises (Bahar et al. 1999).

**3.3.2: Identifying Difficult Topics in Biology - Investigations from Turkey**

Tekkaya *et al.* (2001) carried out an investigation into which topics Turkish students found difficult in Biology. The schools' Biology syllabus was examined and 30 scientific concepts were chosen for the instrument. The instrument had two sections; in the first section the students were asked to determine their level of difficulty in relation to the 30 concepts highlighted. Students were asked to describe the topics using a similar scale as above. The second part of the instrument required the students to explain why they found the topics they highlighted difficult to learn. Table 3.3 shows the topics that students found most difficult to learn.

**Table 3.3 List of Biology topics that Turkish students found difficult to understand and learn**

<table>
<thead>
<tr>
<th>Topics Identified by the students as being difficult</th>
<th>% of pupils that identified topic as being difficult</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hormones</td>
<td>37.5%</td>
</tr>
<tr>
<td>Genes and Chromosomes</td>
<td>35.9%</td>
</tr>
<tr>
<td>Mitosis and Meiosis</td>
<td>34.5%</td>
</tr>
<tr>
<td>Nervous System</td>
<td>33.7%</td>
</tr>
<tr>
<td>Mendelian Genetics</td>
<td>32.1%</td>
</tr>
</tbody>
</table>

The result of the investigation revealed that students found Hormones, Genes and Chromosomes, Mitosis and Meiosis, the Nervous system, and Mendelian Genetics difficult concepts for them to learn. From the second part of the investigation instrument, students stated that they found it difficult to relate hormones to other systems in the body, therefore resulting in memory learning. Similar to the study carried out in Scotland (Bahar *et al.* 1999) Genetics was highlighted as a difficult topic due to terminology, abstract
concepts, and difficulty in carrying out mathematical questions, particularly probability. 34.5% of the students stated they found Mitosis and Meiosis difficult areas in Biology especially distinguishing the different phases (Tekkaya et al 2001).

Cimer (2011) also carried out an investigation into the Biology topics the Turkish students found difficult. A self-administered questionnaire was used including three open ended questions to gather the information from the students. The data was analysed both qualitatively and quantitatively. Of the topics listed five of them appeared to cause the most difficulty and confusion for the students. The topics that students found most difficult are shown in Table 3.4.

Table 3.4 List of Biology topics that Turkish students found difficult to understand and learn

<table>
<thead>
<tr>
<th>Topics Identified by the students as being difficult</th>
<th>% of pupils that identified topic as being difficult</th>
</tr>
</thead>
<tbody>
<tr>
<td>Matter cycles</td>
<td>34%</td>
</tr>
<tr>
<td>Endocrine system and hormones</td>
<td>29%</td>
</tr>
<tr>
<td>Aerobic respiration</td>
<td>26%</td>
</tr>
<tr>
<td>Cell division</td>
<td>24%</td>
</tr>
<tr>
<td>Genes and chromosomes</td>
<td>22%</td>
</tr>
</tbody>
</table>

Although these students identified other topics as difficult, Cell division and Genetics were once again identified as problematic.

3.3.3: Identifying difficult topics in Biology- Examiners Report from United Kingdom

The Examiner’s Report for the General Certificate of Secondary Education (GCSE) 2010 highlighted the topics and corresponding questions that the students found most difficult to answer and comprehend. Again, Genetics proved to be a difficult topic for the students, in particular confusing terms due to the complexity of the language used and the vast amount of it. Similar to the Turkish investigations (Cimer 2011; Tekkaya et al 2001) students
found the questions relating to hormones very challenging in particular questions linked to human reproduction. Students also failed to differentiate between the different transport vessels; xylem and phloem (University of Cambridge International Examinations 2010).

3.3.4: Irish Chief Examiners Report in Biology

It is evident from the above investigations that some Biology topics prove to be more difficult for students than other topics. The Chief Examiner’s report on Biology offers an insight into the performance of Irish students and highlights the topics they find most difficult. The most recent report available for Biology relates to the 2013 exam. So far, reports have been published for five years; 2001, 2002, 2004, 2009 and 2013. Appendix 1 lists the percentage of attempts that were made to answer particular topics in the Higher Level Biology Examinations 2001, 2002, 2004 and 2009. 2013 is discussed in addition to the other four years, as similar information presented in Appendix 1, 2, 3 and 4 wasn’t available for that year. Appendix 2 lists the percentage of attempts that were made to answer particular topics in the Ordinary Level Biology Examinations. The percentage Figures indicate the percentage of all Biology candidates that tried this question in the Leaving Certificate Examination at Higher and Ordinary level.

From Appendix 1 and 2, it can be seen that the short questions for example on Nutrients were one of the most popular questions at higher level in the years 2001, 2002, 2004 and 2009. The least popular questions were; Ecology, Genetics, Transpiration, Enzymes, Microorganisms and the Skeleton. Similarly, the short questions were the most attempted at ordinary level. Genetics and Ecology again appeared to be the least attempted topics along with Photosynthesis, Hormones, Enzymes, Microorganisms, Skeleton, Circulatory system, Nervous system Osmosis and Immunity. In the 2013 exam, a similar trend was
noted for both higher and ordinary level in relation to previous years, short questions on Nutrients were the most often attempted while questions on the Reproduction of a flowering plant, Ecology, Microbiology, Immunity, Plant growth regulators and the Endocrine system were avoided. Appendices 1 and 2 indicate the topics that both higher and ordinary level Biology students avoid. It is unlikely that students will attempt questions that they find difficult. This leads us to belief that Irish students have difficulty with the listed topics (Appendices 1 and 2). Some of the topics identified correlate with the results obtained from the investigations carried out by (Bahar et al 1999; Cimer 2011; Tekkaya et al 2001).

Appendices 3 and 4 list the average percentage Irish students obtained in each particular question in the years 2001, 2002, 2004 and 2009 in higher and ordinary level Leaving Certificate Biology exams. The data has been gathered from the Chief Examiners report in Biology for the five years; 2001, 2002, 2004, 2009 and 2013.

From analysing the average results obtained over the five years, it is evident that both higher and ordinary level Biology students found it difficult to achieve high grades in questions relating to 16 out of the 32 topics examined in Leaving Certificate Biology which accounts for 50% of the content studied (Ecology, Genetics, Transpiration, Enzymes, Microorganisms, Photosynthesis, Respiration, Hormones, Microorganisms, Skeleton, Circulatory system, Nervous system, Osmosis, Immunity, Germination, and Skin). Although the percentage of students that attempted questions on Ecology was quite low, the average percentage they achieved ranged from 52% to 82%. Therefore, it is assumed that the stronger academic students attempted these questions. In addition, it is well documented that Plant topics are the least often attempted and most poorly answered
(State Examination Commission 2013). The fact that these questions are not popular and do not rank high on the average percentage scale for both higher and ordinary levels may be an indication that Irish students have difficulty with these particular topics.

3.3.5: Summary of Research into Identifying Difficult Topics in Biology

From examining the Chief Examiners reports in Biology as well as the investigations carried out in Scotland, Turkey and England it can be noted that Genetics, Hormones, Cell Division and the Nervous system are perceived to be difficult topics across the board. While Ecology, Transpiration, Enzymes, Microorganisms, the Skeleton, Photosynthesis, Circulatory system, Osmosis and Immunity were highlighted as a difficult topics for Irish students, this was not highlighted by the investigations carried out in Scotland (Bahar et al 1999), Turkey (Cimer 2011; Tekkaya et al 2001) and England (University of Cambridge International Examinations 2010). These investigations can offer useful information as they indicate topics that students find the most difficult. However, studies specific to the Irish Biology student is necessary for this research in order to define the exact topics that are opposing difficulty and to determine the reasons why Irish students find these particular topics challenging.

3.4: Why is Biology Difficult?

It is evident from the previous section that students find aspects of Biology difficult to learn. Table 3.5 highlights a number of causes of difficulty in Biology which have been found by the corresponding researchers.

Table 3.5 Causes of difficulty when learning Biology

| The Reasons why Students’ find certain Biology Topics Difficult to Learn |
|---------------------------------|-------------------------------------------------|
| **Language** – can be complex, large vocabulary | (Bahar et al 1999) |
| **Mathematical content** – expressions and symbols | (Bahar et al 1999; Haambokoma 2007) |
| General attitudes – intrinsic interest, negative attitude | (Bahar et al 1999) |
| Three different thought levels - the Macro and tangible, the Micro and the representational | (Johnstone 1991) |
| Inadequate explanations – inability of teachers to explain adequately to learners | (Haambokoma 2007) |
| Time allowance – not enough time allocated to discover and unfold difficult topics | (Bahar et al 1999) |
| Topic not taught and scheduling of topic | (Haambokoma 2007) |
| Lack of learning resources | (Haambokoma 2007) |
| Lack of practical activities | (Haambokoma 2007) |
| Information overload - terminology | (Haambokoma 2007) |
| Sequence of topics in Biology textbooks | (Tolman 1982) |
| Relationships between different concepts in the textbooks | (Capa 2000) |
| Importance of Figures – Biology learning is enhanced if clear and relevant Figures are used along with text | (Kearsey and Turner 1999) |
| Abstract nature of certain Biological topics | (Tekkaya et al 2001) |
| Unfriendly attitudes of teachers | (Haambokoma 2007) |

Bahar et al (1999) highlighted that the language used in topics like Genetics, Photosynthesis and Respiration can be very complex. This in turn leads to the students having a lack of confidence in the meaning of the different terms and experiencing information overload. Mathematical content such as symbols and problems can prove difficult for students that are weak at Mathematics (Bahar et al 1999).

If students enter the classroom with a negative attitude on the topic it can be difficult to shift this attitude resulting in students effectively being disinterested in class. If students are not interested they tend to approach the topic with less eagerness and persistence (Maqsud 1992). A positive attitude is an important pre-requisite to learning (Reece and Walker 1997). Similarly, if teachers have a negative attitude and tell the students that the topic is difficult, this will discourage the students from learning (Haambokoma 2007).

When teachers are unapproachable in the classroom students are afraid to ask questions for fear of getting in trouble. This again reduces the learning achievement of the students, as asking a question is an important aspect of the learning process (Petty 1993).
Teachers’ lack of subject content knowledge can invariably lead to inadequate explanations. Teachers’ explanations have a major effect on the learning and understanding of the information (Hashweh 1987). The quality of the education system cannot exceed the quality of the teachers and the only way to improve the outcomes is to improve the instruction (Malm 2009). Some topics are left to the end of the term to be covered because teachers aren’t comfortable teaching the topics. Teachers tell the students to read over the topic themselves as it is getting close to end of term exams and they have run out of time to teach it. Topics such as Genetics can be very difficult for students to understand by reading it on their own (Hiebert 1999).

Presenting information too fast in Biology also has a huge effect on students learning; students struggle to keep up, especially lower ability students, and they lose interest in the topic (Reece and Walker 1997). In addition, when information is given to students too quickly they don’t have enough time to retain it as it cannot be processed by the short time memory (Petty 1993). It has been noted that reducing the amount of instructional time and learning activities reduces the learning achievement of the student (Maranzo 2000).

It is important that teachers stress the relationships between different concepts, for example, Meiosis and Genetics (Capa 2000) to increase the students’ understanding of the topic being taught. Finally, teachers need to appreciate the importance of figures in textbooks, as Figures play a vital role in the explanation, contextualisation and illustration of the text which in turn enhances the learning of the students (Kearsey and Turner 1999).

3.4.1: Difficulties Caused by the Nature of Biology

One of the main reasons that some Biology topics are difficult is because the ideas and concepts associated with them exist on three different thought levels: the Macro and Tangible, the Micro and the Representational (Johnstone 1991).
The Macro and Tangible relates to phenomenological: which means what can be perceived by the senses without the use of instruments. For the most part it is concrete (Mbajiorgu and Reid 2006).

The Micro level refers to what can only be perceived with the aid of instruments. This is generally abstract (Mbajiorgu and Reid 2006).

The Representational level which is sometimes referred to as the symbolic level refers to symbols, models and equations (Mbajiorgu and Reid 2006).

Multilevel thought was first introduced by Alex Johnstone in 1984 (Johnstone 1991). He represented the three levels of thought using the three points of a triangle, seen in Figure 3.3.

Figure 3.1 Three levels of thought (Johnstone 1991)

The triangle explains how Biological concepts move from one level to the other in the mind of the learner. For example, in Genetics observing the morphological characteristics of an animal is the Macro level as it is accessible to the learner via their senses. The use of the words alleles and genes to explain the Macro brings the learners to the Sub-micro level as the concept isn’t directly accessible to their senses. Finally, alleles are then represented
and manipulated using mathematical content which is symbolic of the Sub-micro level hence it is called the Symbolic level (Bahar et al 1999).

The teacher is equipped to move intellectually between the three corners of the triangle as well as operating within the triangle when it is required to use all three levels of thought in different proportions (Bahar et al 1999). However, students do not share this ability. Students will begin by operating at one level at a time and as time goes on they can operate both the Macro level and sub-micro level quite well. It can take a long time before students can move between the three levels and work within the triangle. Students have great difficulty in working in all three levels at the same time (Mbajiorgu and Reid 2006). It has been noted that the difficulties associated with Science learning occurs because the majority of teaching is carried out within the triangle, where the three levels are required in varying proportions and many teachers are unaware of the challenges this poses on students (Johnstone 1991).

3.5: LEARNING

Learning is a rather complex phenomenon; the students in a classroom are very different and difficult to cater for effectively. Multi perspective views of learning need to be developed (Treagust and Duit 2009). A multiple perspective takes into account different components such as affective, emotional, intentional aspects of learning, social situation, kinaesthetic perceptions, type of knowledge or types of lexical and syntactical forms of language. This leads to curricular aspects of planning in education such as teaching and learning with diverse learners having different skills and interests, gender, multicultural background and inclusion of all types (Taber 2012). Learning is always deeply shaped by the particular social and material characteristics of the learning environment. Hence, a
discourse either in small groups or the classroom is essential for the quality of the learning outcomes (Vosniadou 2008).

Our previous knowledge and learning has a huge influence on our new learning (Johnstone et al 1998). Elaborative rehearsal is essential in retaining information in the short term memory. One needs to use information stored in the long term memory to add details to new information, clarify the meaning, make references, construct visual images and create analogies (King 1992). It is important for the learner to see the meaningfulness in the information they are presented with. This is more likely to occur when a more knowledgeable and skilled individual explains to a less knowledgeable individual (Lovatt 2009). Previously stored information is important during the learning process as we look for connections in our long term memory to help us understand and fix on our new information (Johnstone 2000). It is here where many students’ misconceptions are left embedded and won’t be overcome unless their knowledge is conceptually tackled. The Biology teacher cannot underestimate the effect of previous experience and ideas on the current learning of the student. Meaningful learning, which occurs when new information can be related to existing knowledge, is much more resistant to forgetting than is rote memorisation. Thus, using examples, analogies, explanations and imagery can help increase the chances for meaningful learning to occur (Morrison et al 2011).

The main emphasis of research is to restructure pre-instructional structures of learners in order to allow understanding of the science concepts under consideration (Treagust and Duit 2009). The classical notion of conceptual change (Posner et al 1982) trying to replace or eliminate misconceptions by new and better science conceptions is fundamentally misleading. The problems with teaching through setting up cognitive conflict/dissonance,
because although the brighter, more successful students could react enthusiastically to
cognitive conflicts, the unsuccessful students can develop negative attitudes and try to
avoid conflicts (Clement 2008). Vosniadou (2008) proposes a view of learning science as
a gradual process during which initial conceptual change structures based on children’s
interpretation of everyday experience are continuously enriched and restructured.
Conceptual change is achieved gradually as new ideas are added onto existing but
conflicting conceptual structures sometimes enriching them and sometimes fragmenting
them (Vosniadou 2012). Individuals are not simply passive learners but make sense of
new information in terms of their previous ideas and experiences (Treagust and Duit
2009). These misconceptions can be firmly held and are resistant to change which presents
difficult challenges for Biology teachers and researchers of science education.

3.5.1: Constructivism and Conceptual Change

Ideas of constructivism help to explain how learners develop their understanding of
scientific phenomena. Constructivism emphasises that knowledge is not received
passively but is built up by the cognising subject and that the function of cognition is
adaptive and enables the learner to construct viable explanation of experience (Driver
1989; Treagust et al 1996; Treagust and Duit 2009). Constructivist teaching approaches
consider students’ beliefs and conceptions towards student-centered pedagogy in science
instruction with the focus on the students, their interests, their learning skills, and their needs
in actively constructing their knowledge (Treagust and Duit 2009). During the past 40
years conceptual change developed in three phases: In the 1970s the idea dominated to
eliminate or to replace “old” everyday conceptions or pre-instructional conceptions in
favour of the intended science concepts. It followed a phase of social constructivism
leading to the notion of learning in a social environment. Now, researchers of students’
conceptions and conceptual change have conceptualised learning as being embedded in various theoretical frameworks with epistemological, ontological and affective orientations (Duit and Treagust 2009; Taber 2006; Taber 2012). Other studies on conceptual change emphasise the importance of the role of the learner, suggesting that the learner can play an active international role in the process of knowledge restructuring (Sinatra and Pintrich 2002).

Constructivism pays particular regard to the existence of students’ prior knowledge when entering a learning environment (Hare and Graber 2007). In order to promote meaningful learning, teaching methods must be found to recognise, reduce and ultimately remove students’ misconceptions through conceptual change; an active process where learners become aware of and reason for conceptual relations (Alparslan et al 2003; Brody 1994; Ritchie 1994). Conceptual change strategies represent an alternative approach to Science teaching which encourage students to change and restructure their misconceptions (Hewson and Hewson 1983; Smith et al 1993).

For teachers to implement conceptual change strategies amongst their students, they need to possess a very high standard in their content knowledge, pedagogical content knowledge and a high degree of awareness of each individual student’s misconceptions (Diakidoy and Iordanou 2003; Gomez-Zwiep 2008). Students should be encouraged to construct their own knowledge and skills through active processing, rather than being passive listeners. The students need to be viewed not as a passive recipient of knowledge but rather as an active participant in its creation (McDermott 1997). However, care must be taken when using this constructivist approach as attempts by students to understand new knowledge may cause the development of misconceptions if the class isn’t facilitated properly (Hare and Graber 2007). There are a number of methods cited in the literature
which outline how students can achieve conceptual change. For example by asking students to participate in projects, to solve complex problems, to design and execute experiments, to think about their ideas and to listen to the ideas of others (Alparslan et al 2003).

Once teachers have identified the misconceptions, it is necessary to provide an opportunity for the students to confront their misconceptions and assist their students in reconstructing their knowledge (National Research Council 1997). By simply listening to student’s responses and explanations, one can determine if the students’ level of understanding is “deep” or “superficial” (Gooding and Metz 2011). As a teacher, the task of giving students the opportunity to clarify their responses is extremely important. Students should be given sufficient time to evaluate the information so that they will be prepared for any higher order questions posed to them. It should also be noted that as a teacher one should not try to always seek the “right answer”. Instead, a teacher should use students’ responses and build on these (Gooding and Metz 2011). Although this is deemed the best approach, it was found that this can be frustrating as students have a tendency to revert to their own ideas even after such participation and so may lead to the formation of misconceptions (Watson and Konicek 1990).

3.5.2: Student Approaches to Learning

There are two approaches to learning that students can adopt; a ‘deep approach’ or a ‘surface approach’ (Maton and Saljo 1976). The approach to learning that the student decides to take or is influenced to take will impact on the outcome of the learning achieved. Deep learning corresponds to real understanding while surface learning is being able to imitate or reproduce what has been taught with little or no understanding of the concept (Ramsden 1992). A deep approach occurs when the student has the opportunity to
actively engage in a task which leads to long term storage of the learning and in-depth understanding. It involves integrating previous stored beliefs to link ideas and the ability to see various patterns from different concepts (Mintizes et al 2005). The surface approach refers to students obtaining the information for a short period of time with no organisation placed on the concepts therefore, making it impossible to relate back to in the future as no connections were made. Surface approach to learning merely results in rote memorisation and short term recall (Harlen and James 1997).

3.5.3: Effective Learning in Classrooms
Classrooms are complex places. Promoting a positive and engaging learning environment can be a difficult process for teachers to develop due to many constraints such as; curriculum setters, accountability and performance, material overload and lack of time. However, it is crucial to effectively promote their students’ learning. There are many types of effective learning strategies mentioned in the literature that should be implemented where possible, active and collaborative learning are discussed below. When learning is visible the teacher knows if learning is occurring or not. Learning is visible when the learning goal is not only challenging but is explicit. The greatest effects on students learning come from when learners become their own teachers through self monitoring and self assessment and when the teachers become learners of their own teaching (Hattie 2013).

3.5.3.1: Active Learning
If students are to really learn and understand what they are being taught, teachers need to move away from the traditional didactic style teaching and engage students as active learners in the classroom (Asay and Orgill 2010). Active learning can be defined as a type of instruction where by the student is actively engaged and involved themselves in their
own learning (Prince 2004). It is well documented that students perform significantly better when engaged in an active learning environment (Burrowes 2003; VanderStoep et al 2000; Watkins et al 2007). Science can easily be related to real life examples making Science teaching an ideal discipline for incorporating active learning (O’ Grady et al 2014). Knowledge should be actively constructed by the learner, in relation to previous knowledge and not passively received from the environment. Students should be active in their reading, writing, listening and experimenting. Teachers need to fully understand the difference between students that are active in class and active learning in order to generate the most beneficial effects of the methodology (Ford and Wargo 2012). It is the teachers role to facilitate active learning by encouraging and eliciting the learners’ interpretations meaning making. In addition, teachers need to overcome the constraints (time, curriculum setters, and overloaded syllabus) with the help of curriculum setters and policy makers and embrace change as professionals.

3.5.3.2: Collaborative Learning

Classrooms have the potential to be very social, however for the most part the social aspect does not exist, students learn individually. Collaborative learning is when people work together sharing each other’s thoughts and ideas with a sense of creating something greater that wouldn’t be as successful created separately (Tiessen and Ward 1997). Communication is a key element for cooperation and collaboration to be effective among students and students and their teachers. When students share their meaning making of a particular concept with others it is found to make their learning deeper and richer (King et al 1998). Vygotsky (1978) further supports this methodology that new knowledge and ideas develop best in a context of dialogue. The “think, pair, share” structure (Lyman 1981) promotes the sort of talk and interaction which are needed for initial collaboration
however, more creating and discussion must be further incorporated to really benefit from the experience (Watkins et al 2007). Collaborative learning will not happen effectively if not planned efficiently by the teacher. Teachers can also learn from other teachers, it is more sustainable and innovations are better supported when teachers work and collaborate alongside other teachers in their subject area. Collaboration allows teachers to hear new ideas, deal with doubt talk through uncertainty and understand change (Carnell 2001).

3.5.4: Assessment and Learning: Emphasis on Terminal Examinations

Assessment is a fundamental part of teaching and learning (Cheng and Cheung 2001; Ling and Towndrow 2006). It is used for grading and classifying students, as a tool to evaluate learning and teaching effectiveness (Gibbs and Simpson 2004). There are two main types of assessment; summative assessment and formative assessment. Formative assessment helps students identify and correct their errors aiding in the progression of future learning. While, summative assessment may inform teachers where their teaching needs to be adjusted but for the students the only feedback they receive is a grade which does little, if anything to aid them in the development of their conceptual understanding and future learning. The Senior Cycle Biology examination is summative in nature.

One of the major problems associated with the teaching and learning of Biology is the tendency of both curriculum setters and teachers to focus on the excessive use of facts and information often telling students what they need to know through lecturing or didactic style of teaching (Lord and Baviskar 2007) and students are merely recalling the information in the test. Teachers are teaching for the examination, and teach the skills only required by the students for that examination, rather than the skills required for lifelong learning and holistic development (Cheng and Cheung 2001). Often due to time constraint of the academic year, syllabi are delivered to students where they gain the
knowledge of the course but often the students do not have a full understanding of the material. It has been well documented that such an excessive use of facts results in the use of rote learning to gain knowledge in relation to biological concepts. Rote learning of such concepts results in a poor level of higher cognitive understanding of complex Biological concepts (Barnes et al. 2000). It is often associated with the remembrance of knowledge at the lowest level of Blooms Taxonomy – recall (Momsen et al. 2010). In cases such as this, misconceptions are not challenged or brought to light, allowing learners to hold onto their misconceptions throughout their formal education. Students simply ‘learn’, off by heart, what is required of them to get them through the exam (Mintzes et al. 2001). Despite this being one of the founding reasons for the high level of participation of Biology with students over the physical Sciences, it is also strongly associated with the reasoning behind students having difficulties gaining a good conceptual understanding of complex biological concepts. The strong tendency to focus on recall and didactic teaching methods within the field of Biological education in particular leads to poor depth of knowledge (Allen and Tanner 2005).

3.5.5: Factors Influencing Student Learning

It is evident that there are a number of factors that influence students’ learning; learners previous knowledge, how learners perceive information, how learners’ construct new knowledge and reconstruct previous beliefs (Lovatt 2009). The teacher is one of the predominant influences of successful learning and it is therefore their role to ensure they’re aware of factors that influence students’ learning and how these factors impact on the way they teach so they can improve their students’ learning. Several factors influence students’ learning; how motivated and interested they are in the subject (Pintrich and Schunk 1996) and the learning environment they are surrounded by (Lovatt 2009).
According to the literature, there has been a decline in the student interest in Science subjects due to difficulty in obtaining a good grade in terminal examinations compared to other senior cycle subjects (Hayes and Childs 2010); Accounting and Geography (State Examinations Commission 2013). Gender balance and attitudes towards Science is also to the forefront in research, developing appropriate innovative pedagogies are needed (Daniels 2001).

3.6: TEACHING AND PEDAGOGY

Being a teacher is a difficult role to play, especially when confronted with the complex demands of everyday life in schools (Biesta and Miedema 2002). It needs to be acknowledged that the task of the teacher and the school is first and foremost a pedagogical task, as it is concerned with the whole person, the whole sense of identity of the student. An important implication of the conceptual change approach is that participation is seen as a process in which the whole person is involved, not only his or her cognition, but also his or her feelings, beliefs, attitudes, values, emotions, volitions, habits, predispositions, and actions (Biesta and Miedema 2002). However, teachers are not well informed about the recent state of research on teaching and learning and hold views that are predominantly transmissive and not constructivist (Treagust and Duit 2009).

3.6.1: Didactic Teaching-An Outdated Approach

Science teaching often involves the presentation of a rigid body of facts, theories, and rules to be memorised and practiced, rather than a way of knowing about natural phenomena (Van Driel et al 2001). This traditional view of education involves methods of instruction that consider the students’ mind as a blank slate for which the teacher is to transfer knowledge directly and intact. This view of education takes no consideration for any prior knowledge a student may hold (Barr and Tagg 1995; Bodner 1986). Research
into this traditional use of teacher-directed, didactic methods of instruction has shown that students gain a poor acquisition of scientific concepts from this approach (Alparslan et al 2003). Traditional approaches to teaching and learning encourages learners to resort to rote-learning techniques which require the lowest level of cognitive skill, knowledge. According to Bloom’s Taxonomy (1973), which divides the skills in the cognitive domain into six levels; knowledge, comprehension, application, analysis, synthesis and evaluation, ‘knowledge’ is the lowest and least challenging level of the cognitive domain (Gray and Waggoner 2002; Zoller 1993). Unfortunately, Science teaching in Ireland has been traditionally very didactic (Forfás 1999).

In this environment, the teacher is the centrepiece for instruction while the students absorb information and regurgitate it in order to complete an exam based assessment. This type of environment provides incentives for learning at surface level only by encouraging students to learn superficial indicators of knowledge rather than an understanding of fundamental principles (McCarthy and Anderson 2000). It stifles creativity and is no longer sufficient for educating a classroom of students (Zhao 2003). It is important that teachers are made aware of the limitations of the didactic approach of teaching. Covering a syllabus or textbook does not mean that the result will lead to meaningful learning (Cheng and Cheung 2001). As soon as we acknowledge that meaning is not something that we passively receive but rather something we actively ascribe or assign to something, it becomes clear that the transmission model omits the most crucial part of human communication where misunderstanding is always a possibility (Derrida 1998). Mintzes et al (2001) found that there is a growing recognition among Biology teachers and educational theorists of the need to refocus classroom efforts on meaningful learning and conceptual understanding of scientific principles rather than teaching and learning.
isolated pieces of “inert knowledge.” Advocates of this approach state the need for “quality over quantity, meaning over memorising and understanding over awareness.” The goal should be to encourage students to construct useful knowledge that they can apply in the real world. Despite the efforts of creative teachers and curriculum designers, the majority of students leave secondary school with a distorted view of Biological concepts and events due to time constraints and a ‘packed’ syllabus as discussed in chapter 2; school culture and reform. To ascertain teaching for understanding teachers should be taught how to think and practice assessment techniques for understanding and move away from teaching solely how to present a curriculum during their teacher education (Tomanek et al 2008).

3.6.2: Conceptual Change and Constructivism

Studies suggest that all teachers need to find appropriate ways to recognise and confront their own misconceptions, and become supported in this regard in teacher education programs, before they can effectively assist students (Burgoon et al 2011). Teachers need have good subject matter knowledge, so that they can help students create useful cognitive maps, relate ideas to one another, and address misconceptions (Darling Hammond 1998). Achieving high levels of student understanding requires immensely skilful teaching and schools that are organised and prepared to support teachers’ continuous learning (Darling Hammond 1998). Therefore, in order for teachers to implement conceptual change strategies with their students, it appears they themselves need to possess a high standard of disciplinary content knowledge and a high degree of awareness of each individual student’s misconceptions (Gomez-Zwiep, 2008). Once their students’ misconceptions are recognised and diagnosed, teachers need to provide multiple opportunities in the classroom for students to confront misconceptions for their reduction and possible
elimination through reconstructing new scientifically accurate conceptual knowledge (National Research Council 1997; Modell et al 2005).

It can be difficult for science teachers to implement effective active learning strategies in this regard without themselves engaging in a multiplicity of educative opportunities, such as, dialogue, reflective practice, argumentation, meaningful guidance, and access to research literature (Keys and Bryan 2001). That said; it is also well documented that at times teachers can have a limiting role in formulating educational policy (Lang 2003). Science teacher higher education programs need to interrupt the cycle of misconceptions and proactively assist pre-service teachers develop effective practices to identify, reduce and improve the probability of eliminating misconceptions (Asay and Orgill 2010; Driver et al 2000). Deliberative models of curriculum innovation, mentoring and support for teachers using a number of scaffolds and supports, such as, school-university partnerships, have been shown to build ethical trust and ownership of the change process (Galvin et al 2015).

Good settings for teacher learning to occur in both universities and schools provide lots of opportunities for research and inquiry, for trying and testing, for talking about and evaluating the results of learning and teaching (Miller and Silvernail 1994; Darling Hammond 1998). Teachers collaborating with different schools and universities in such a process; requires new skills and roles for teachers which lie beyond a specific classroom level. Within this context collaboration crossing boundaries of science subjects is dependent on teachers, teacher educators and researchers. It is not the individual, isolated, specialist teacher of hard sciences in the classroom but the teacher leader with professional, social and communicative interests who can promote student progress and
better learning results (Riel and Becker 2000). The University of Limerick have been involved in developing awareness of inquiry among pre-service teachers and qualified teachers and it has successfully transitioned into the classrooms (Lehane et al 2013). This study highlighted the importance of engaging newly qualified teachers in situations whereby they could discuss and share ideas which are essential in developing their pedagogical content knowledge. The pre-service teachers did struggle initially to consider how they could teach topics using an inquiry approach, however the scaffolded peer learning community which they were part of during the study afforded them the opportunity to listen to each other’s ideas while concurrently verbalising their own thoughts. Instead of “spoonfeeding” the pre-service teachers the information, they were responsible for their own learning which is something teacher educators advocate use for with students in the classroom (Moore and Woolnough, 2012). How can one be expected to teach using student led approaches when it is not being enacted as part of their own teacher education and training? Such collaborations and mentoring can develop inquiry orientations which can successfully be enacted in the classroom setting (Lehane et al 2013).

Students are challenged continuously in their science classrooms to comprehend complex biological concepts, teachers need to try and provide guidance for students to support their self-esteem and to nurture their interest in science. Teachers who provide guidance and support help to bridge the gap between the social context of learning and the social context of use (Layton et al 1993). Student’s challenges with learning science become less apparent when the subject content is made relevant to their personal world. Teachers should try to connect the subject content to students’ academic interests by creating a link to the culture of science through technical and social issues, epistemology and the
sociology of science (Solomon and Aikenhead 1994). How effective students are at crossing the boundaries between the world they live in and the world of science will significantly depend on the assistance they receive from teachers and the work of teacher educators, curriculum developers and policy makers (Aikenhead 2001).

Researchers have just started to understand and explore the full implications of the conceptual change approach for the design of curriculum and instruction. In addition there is a significant gap between the theoretical and empirical knowledge and classroom practice (Vosniadou 2008). Even a great deal of instruction can lead to little change, while in other situations small influences can lead to major insights (Brown and Hammer 2008).

Instruction should support students in realising the hypothetical nature of their beliefs and teach them how to test them and evaluate their explanatory power. Students’ views of science concepts have an impact on the way in which they approach learning. If students believe that science provides a true picture of the state of affairs of the world (Driver et al 1994), then they are less likely to develop critical thinking, engage in hypothesis testing or look for alternative explanations. Instruction needs to be developed to help students understand better the nature and function of models and engage in model-based reasoning. This type of instruction cannot be achieved without substantial socio-cultural support. Teachers can provide the socio-cultural environment to encourage comprehension by asking students to participating in a whole class discussions or debates (Hatono and Inagaki 2003; Vosniadou 2012).

3.6.3: Effective Teaching Strategies and Resources for the Intervention

3.6.3.1: Analogies
Analogies were found to be a popular teaching strategy used by researchers to help overcome misconceptions and encourage conceptual change (Clement and Brown 2004).
Analogies represent efforts by the students to connect familiar schemas with new ones, integrating existing knowledge with new knowledge to develop mental models that function as explanatory tools (Glynn 1997). However, it is important to emphasise to the pre-service teachers that analogies need to be carefully thought out to be effective by introducing the target, reminding students about the analogy, identifying relevant features, mapping similarities, indicating where the analogy breaks down and drawing conclusions. It is important to think carefully about each of the similarities and to study the illustration (Glynn and Takahashi 1998). If an analogy is not used carefully, it can be counterproductive, causing students to form misconceptions. All analogies break down in places (Mayo 2001). The primary goal is to make the information more understandable and memorable. An analogy taught during the module was the analogy of the factory and a plant cell (Appendix 31).

3.6.4.2: Concept Cartoons

Concept cartoons are also a very popular and effective teaching strategy that can be used to identify misconceptions (Ekici et al 2007). They can be used for a whole class discussion or small groups and are very simple to create and are a good way to identify and overcome misconceptions (Kabapinar 2009). It is an effective way to explore misconceptions, very versatile, generates discussion, grabs their attention and develops their communication skills as they have to explain why they agree with the particular statement related to the concept cartoon (Ekici et al 2007).

3.6.4.3: Conceptual Change Text

Traditional text is not effective in identifying or overcoming misconceptions therefore it is important that pre-service teachers learn how to use text more effectively in class (Wang and Andre 1991). Conceptual change text makes the reader think about the concepts
he/she knows already compared to the traditional text that states facts, the conceptual text may include a question about the concept to be studied in order to activate misconceptions and cause dissatisfaction with their current conceptions (Balci et al 2006).

3.6.4.4: Concept Maps

Concept maps can be used to introduce, develop and revise what the student knows or doesn’t know and provides students with an easily remembered chart (Novak and Canas 2006). The maps gather thoughts and help to link ideas and concepts together. Formulas, theory, diagrams and imagery can all be linked together to see their relationship (Novak 2010). Concept maps are an effective visual tool for learners, connects prior and new knowledge together, helps in brainstorming and improves the cognitive development of the student (Novak and Canas 2006). However, at senior cycle level it can be difficult for students to construct their own concept maps therefore; teachers could give the students a skeleton of a concept map, leaving out the key words or leaving out the linking words for them to complete. This way, the teacher still assesses their understanding and linking of concepts but is less time consuming and more manageable.

3.6.4.5: Digital Resources

Digital resources, in particular digital storytelling is now being widely used in the classroom (Robin 2008). It can be used to teach new vocabulary using imagery as well as words and sound, create reflective exercises to inspire student creative writing or reflective pieces, create revision reminders or topic summaries using images and sound rather than text alone. Teachers can use these to encourage students to illustrate a particular point of view or statement, for example “Pollution is wrong from the perspective of an animal”. Digital multimedia energises students to create stories as well as learning creative skills (Banaszewski 2002). Through the storytelling process students
also develop skills of reflection to understand the story they’re telling. They’re improving their technology skills, learning the importance of research and for students with English as a second language allows them to reflect on the language and helps develop their oral skills to speak it, hence it is effective in addressing diversity in the classroom. Many students that hear stories more often can better comprehend other materials. Digital resources are engaging and stimulating for the students, create a positive learning environment and promote creativity and imagination (PPDS 2011).

3.6.4.6: Inquiry Based Approach

An inquiry based approach can lead to important outcomes in the classroom (Scruggs et al 1993) and can be enhanced with video clips and stimulations. Students that can actively make observations, collect, analyse, synthesise information and draw conclusions are developing useful problem-solving skills. These skills can be applied to future "need to know" situations that students will encounter both at school and at work. This type of teaching approach encourages creative thinking (Sanger 2008). Experiments can be used to introduce new ideas or to clarify puzzling aspects of topics. Classroom experiments and demonstrations keep learners active and engaged. Students are encouraged to make predictions on experiments and to compare and contrast their results to classroom theories (O’Grady et al 2014).

3.6.4.7: Models

Many aspects of the Biology syllabus are very abstract in nature and are difficult for students to understand with text alone. Models can help to explain the abstract concepts being taught and create a more vivid picture in the students’ minds (Harrison and Treagust 2000).
3.6.4.8: Science Reflective Journals

Science Reflective Journals (SRJ) can be used in the classroom; the teacher teaches a topic while the students write in their SRJ any concepts they are unsure about. At the end of the week the teacher collects them for analysis, the following week the teacher highlights the statements and questions that arose and explores the questions with the students using suitable resources (Towndrow et al 2008). This strategy can be particular useful to students that are less vocal in the classroom.

When the teaching is visible the student knows what to do and how to do it. Teaching and learning are visible when the learning goal is not only challenging but clear. For visible learning and teaching to occur the teacher and the student need to work together to attain a goal, provide feedback, and determine whether the student has achieved their goal or not (Hattie 2012). Teachers need to provide students with opportunities to engage in the learning, explore the concept with other learners, explain their understanding, provide extension if required and evaluate by observing their application of knowledge and change in thinking patterns (Perrone 2007). The greatest effects on student learning come when not only the students become their own teachers but the teachers become learners of their own teaching through reflection and evaluation (Towndrow et al 2008). In successful classrooms both the teacher and student need to be visible (Hattie 2012).

3.7: MISCONCEPTIONS IN PHOTOSYNTHESIS

Although a complete search of prevalent misconceptions in Biology was made on the literature reviewed (Appendix 33) and were used for the diagnosis of the participants misconceptions in phase 1 of the study, it was decided to focus in on one particular topic for the intervention programme. Photosynthesis was selected as it is a prevalent Biology topic many students find conceptually challenging (Marmaroti and Galanopoulou 2006).
Despite the fact that photosynthesis is a foundational topic in the science curriculum, studies show that students often have a very weak understanding (Ekici et al 2007; Kose 2008; Ozay and Oztas 2003).

**Table 3.6 Misconceptions relating to Photosynthesis**

<table>
<thead>
<tr>
<th>No.</th>
<th>Scientific Concept</th>
<th>Misconception</th>
<th>Author</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Plants make their food by a process called Photosynthesis.</td>
<td>Plants obtain their food from the soil. Plants are fed in the same way as humans and animals. Food for the plants is anything taken in from the environment. Soil provides a support structure and food for the plants. Food travels from the roots to all parts of the plant. Plants food is minerals in the soil. The soil supplies water and food for the plant. Plants feed on the bacterial decomposition. Plants get their food from the soil through their roots. Photosynthesis is the means by which plants respire. Photosynthesis is the respiration of plants in light. Photosynthesis is the process by which the plant breathes. Carbon dioxide, water, fertiliser and minerals are food for the plant. Plants get their food from the soil via their roots. Plants take in food from the outside environment, and/or plants get their food from the soil via roots. Water is food for plants. Plants get organic food substances such as sugar and starch or protein from the soil.</td>
<td>(Barker and Carr 1989; Eisen and Stavy 1988; Wandersee 1983) (Driver et al 1994) (Barman et al 2003) (Roth and Anderson 1987) (Roth and Anderson 1987) (Abdullah and Scaife 1997; Kose 2008; Liew and Treagust 1995) (Bahar et al 1999; Osborne and Cosgrove 1983) (Kose 2008) (Tekkaya 2002) (Bell 1985) (Abdullah and Scaife 1997) (Wandersee 1983) (Stavy et al 1987) (Wandersee 1983)</td>
</tr>
<tr>
<td>2</td>
<td>The leaf is the primary site for Photosynthesis but doesn’t just occur here.</td>
<td>Photosynthesis takes place in the leaves.</td>
<td>(Marmaroti and Galanopoulou 2006)</td>
</tr>
<tr>
<td>3</td>
<td>Light is necessary for Photosynthesis to occur.</td>
<td>Photosynthesis can take place in the absence of light.</td>
<td>(Marmaroti and Galanopoulou 2006)</td>
</tr>
<tr>
<td>4</td>
<td>Light from the sun or artificial light from a bulb is necessary for Photosynthesis to occur.</td>
<td>The sun warms the plant and provides the plant with food Sunlight energy and heat is necessary for Photosynthesis.</td>
<td>(Marmaroti and Galanopoulou 2006; Ozay and Oztas 2003; Waheed and Lucas 1992)</td>
</tr>
<tr>
<td>5</td>
<td>Energy is harnessed in Photosynthesis.</td>
<td>Energy is produced not trapped in Photosynthesis.</td>
<td>(Driver et al 1994; Lin and Hu 2003)</td>
</tr>
<tr>
<td>-----</td>
<td>---------------------------------------</td>
<td>---------------------------------------------------</td>
<td>-----------------------------------</td>
</tr>
<tr>
<td>6</td>
<td>Oxygen is a product from the process of Photosynthesis.</td>
<td>Plants need oxygen for Photosynthesis.</td>
<td>(Marmaroti and Galanopoulou 2006)</td>
</tr>
<tr>
<td>7</td>
<td>Plants increase in size because of new tissue.</td>
<td>Plants increase in size because of the nutrients plants produce.</td>
<td>(Bell 1985)</td>
</tr>
<tr>
<td>8</td>
<td>Photosynthesis is the way plants make their own food.</td>
<td>Photosynthesis is a type of respiration.</td>
<td>(Stavy et al 1987)</td>
</tr>
<tr>
<td>9</td>
<td>Accessory pigments absorb green light and pass that energy on to the chlorophyll for Photosynthesis.</td>
<td>Leaves reflect all green light and do not use green light in Photosynthesis.</td>
<td>(Hershey 2004)</td>
</tr>
<tr>
<td>10</td>
<td>Plants need to Photosynthesise to stay alive.</td>
<td>Plants don’t need any food.</td>
<td>(Ekici et al 2007)</td>
</tr>
<tr>
<td>11</td>
<td>Water and Carbon dioxide taken into the plants are changed into different molecules as a result of a chemical reaction. They are changed to support one life process.</td>
<td>Water and carbon dioxide taken into plants are not changed. They are used unchanged to support two separate life processes.</td>
<td>(Roth and Anderson 1987)</td>
</tr>
<tr>
<td>12</td>
<td>Glucose and oxygen are produced at the end of Photosynthesis.</td>
<td>Carbon dioxide and Chlorophyll are produced at the end of Photosynthesis.</td>
<td>(Ekici et al 2007)</td>
</tr>
<tr>
<td>13</td>
<td>Photosynthesis only occurs in the presence of sunlight or artificial light from a bulb. Carbon dioxide is taken in and oxygen is given out.</td>
<td>While Photosynthesis in plants is the taking in of carbon dioxide &amp; giving off of oxygen during the day, it is the taking in of oxygen and the giving off of carbon dioxide at night.</td>
<td>(Maskill and Cachapuz 1989; Prokop and Fančovičová 2006)</td>
</tr>
<tr>
<td>14</td>
<td>Plants take in carbon dioxide, a chemical reaction occurs and oxygen is one of the products produced.</td>
<td>Plants take in carbon dioxide and change it to oxygen.</td>
<td>(Liew and Treagust 1995)</td>
</tr>
<tr>
<td>15</td>
<td>The factors necessary for Photosynthesis are; chlorophyll, light, carbon dioxide, water and temperature.</td>
<td>Plants can make their food at anytime.</td>
<td>(Roth and Anderson 1987)</td>
</tr>
<tr>
<td>16</td>
<td>Plants are called producers because they make their own food.</td>
<td>Plants are called producers since they are food and oxygen sources for the other organisms. Plants are called producers since they give fruits and vegetables to humans.</td>
<td>(Martlew and Connolly 1996; Thomas and Silk 1990) (Prokop and Fančovičová 2006)</td>
</tr>
<tr>
<td>17</td>
<td>Chlorophyll is a green pigment found in chloroplasts and it absorbs the sunlight to make glucose.</td>
<td>Chlorophyll pigment is a reactant or product of Photosynthesis.</td>
<td>(Marmaroti and Galanopoulou 2006)</td>
</tr>
<tr>
<td>18</td>
<td>All plants that contain chlorophyll can carry out Photosynthesis.</td>
<td>Only green plants can carry out Photosynthesis.</td>
<td>(Tekkaya 2002)</td>
</tr>
<tr>
<td>19</td>
<td>A few hundred parasitic species lack chlorophyll and are therefore not photosynthetic.</td>
<td>All plants are photosynthetic.</td>
<td>(Hershey 1999)</td>
</tr>
<tr>
<td>20</td>
<td>Glucose is not the major</td>
<td>Glucose is the major</td>
<td>(Storey 1989)</td>
</tr>
</tbody>
</table>
The processes of photosynthesis play an important role in understanding many aspects of living systems (Deshmukh 2012; Mikkila-Erdmann 2001). The literature review identified four key areas in which students and teachers commonly held misconceptions: the location of photosynthesis in plants, where a plant gets energy for photosynthesis, where plants get carbon from, and the relationship between cellular respiration and photosynthesis. In relation to the location of photosynthesis students and teachers were found to hold common misconceptions that photosynthesis only occurs in the leaves of the plant (Boomer and Latham 2011). Although, it is true that the majority of photosynthesis occurs in the leaves students and teachers alike needed to comprehend that photosynthesis also occurs in any chloroplast that contains chlorophyll. Labelled diagrams in textbooks were found to be a strong source of this misconception (Clegg 2011; Marmaroti and Galanopoulou 2006). The second area was in relation to where the plant gets energy. Misconceptions were often related to a misunderstanding between energy and nutrients: ‘Plants obtain their food from the soil’, ‘Plants are fed in the same way as humans and animals’, ‘Food for the plants is anything taken in from the environment’, ‘The soil supplies water and food for the plant’ and ‘Carbon dioxide, water, fertiliser and minerals are food for the plant’ (Deshmukh 2012; Ekici et al 2007; Ozay and Oztas 2003). While some students appeared to be aware that the sun is necessary for photosynthesis they were less certain of its specific role (Prokop and Fančovičova 2006). A third misconception identified was how plants use and store energy. Many students appeared unsure (Balci et
al 2006; Lin and Hu 2003), believing that the sun provides the plant with warmth, and once used by the plant this solar energy was either lost or destroyed (Carlsson 2002; Ekici et al 2007; Marmaroti and Galanopoulou 2006). The fourth misconception was related to the source of carbon. Carbon in the form of carbon dioxide from the atmosphere is taken in by plants, along with water, and used to produce carbohydrates and oxygen. This was a challenging concept for many, students were invariably given different versions of the processes involved, and many remained confused in relation to the pathways involved (Ekici et al 2007; O’Connell 2008). Finally, students and teachers were found to confuse photosynthesis with cellular respiration. There was evidence of a tendency to regard cellular respiration as synonymous with breathing, therefore it would only occur in organisms with lungs (Marmaroti and Galanopoulou 2006; Mikkila-Erdmann 2001). Common misconceptions cited in the literature were: ‘Photosynthesis is the means by which plants respire’, ‘Photosynthesis is the respiration of plants in light’, ‘While photosynthesis in plants is the taking in of carbon dioxide & giving off of oxygen during the day, it is the taking in of oxygen and the giving off of carbon dioxide at night’, ‘Photosynthesis is the process by which the plant breathes’, ‘Both processes are solely the kind of gases exchange’, ‘Plants only respire at night’ and ‘Respiration is the reverse of Photosynthesis’.

3.8: Successful Science Intervention Programmes

Research has been carried out in relation to the students’ thinking skills and the development of their cognitive ability (Bandura 1993; Snowman and Biehler 2006; Sprinthall et al 1998). There have been a number of programmes implemented into schools to help develop and improve students’ thinking ability as a lot of the subject matter can be quite abstract and many students are still only at the concrete operational
stage of development (Berk 2005; Shayer et al 1976). The cognitive ability of students in the UK was first investigated in 1973 through Science Reasoning Tasks. There were seven tasks developed to assess the ability of the students. The results found that at the age of 15 as little as 10% of the students had reached the formal operational stage (Shayer et al 1981). It was evident that the curriculum demands didn’t match the capability of the students (Adey 1999).

In response to the British Science Curriculum, an intervention programme was developed. The Cognitive Acceleration through Science Education (CASE) project, which aims to promote formal operational thinking, is a successful Science intervention programme (McGuinness 1999). CASE is a teaching approach, based largely on the work of Piaget and Vygotsky’s theories of learning. The CASE programme aims to improve students’ thinking ability and help them reach the formal operational stage (Adey 1999). CASE aimed to develop the cognitive ability of the students in the hope of bettering the students understanding of the material they were being taught (Adey et al 2002).

The CASE programme was carried out over two years and over the two years students completed 32 lessons. The title given to the programme of lessons was ‘Thinking Science’. Over the two years students participated in one lesson every two weeks. Within the CASE lessons students are presented with problems that they have to discuss and solve as a group, the material is challenging as the problems can’t be solved using their current strategies (Adey 1999).

It was found that students in eight different British schools who took part in the ‘Thinking Science’ programme achieved much higher grades in Science than non-participants. The results obtained in the UK schools indicates that the thinking capacity of students can be
enhanced by intervention programmes over a considerable length of time (Endler and Bond 2001).

Similarly in Ireland, it had been noted that students were experiencing cognitive difficulties in understanding Science (Maume 1998). Maume (1998) carried out research in implementing the CASE programme in the first year of secondary school. One class of first year students were used as the experiment group. Thirty CASE lessons were conducted over the year. The cognitive ability of the students was examined again, using Science Reasoning Tasks (National Foundation for Educational Research 1979). It was found that an increase in cognitive ability had occurred among the experiment students compared to the control students. It was noted that the cognitive ability of the students that took part in the programme was significantly higher than the non-participants. Results therefore prove that it is possible to implement CASE materials into an Irish second level classroom over a short period of time and have positive results (McCormack 2009). Studies in Chemistry education by Childs and Sheehan (2009) and Sheehan (2010) in second and third level and McCormack (2009) at primary and early second level found that CASE lessons also had a very positive effect on Irish students’ cognitive development.

Endler and Bond (2001) carried out an investigation to examine the cognitive development of students over a five year period and the influence the CASE Thinking Science programme had on them. Teachers conducted one lesson every three weeks with this group of students aged 8-12. Bond’s Logical Operations test (paper and pencil test) was used to measure the effectiveness of the intervention programme (Bond 1976). The results showed noteworthy increases in the cognitive development of the students that
participated in the intervention lessons over the five years compared to the non-participants.

Endler and Bond (2007) carried out further research in the USA where they again implemented the CASE programme to address students’ capability in scientific inquiry. The USA version of the CASE programme was titled the ‘Scientific Thinking Enhancement Project’ (STEP). In this particular CASE programme, teachers decided themselves how often their students would receive the STEP lessons; on average they had one every three weeks. Results yet again were positive for the CASE intervention. By the end of the study, the STEP cohorts were at a higher mean cognitive developmental level than the control sample (McCormack 2009).

3.8.1: Development of an Intervention Programme to Overcome Misconceptions in Photosynthesis

The European Commission (2007) suggests that improvements in Science education should be brought about through new forms of pedagogy. This is evident from the successful intervention programmes mentioned above as by changing the pedagogy students were able to reach the formal operational stage faster and as a result understood the material better. New teaching and learning strategies need to be incorporated to attempt to identify students’ and their teachers’ misconceptions. Strategies that will address their conceptual understanding and advance their learning need to be created and implemented. Efforts have been made to date in relation to possible suggestions to tackle and overcome them; however, the persistence of misconceptions reflects the limited success of attempts made. Improvement is needed and strategies need to encourage students to comprehend the uncertainty of Science and the importance of inquiry and problem solving. Students need to be encouraged to really understand. It is therefore
proposed that an intervention programme will be developed and implemented into Irish secondary schools and teacher education programmes in the University of Limerick. The intervention programme will focus on the senior cycle Biology syllabus. It will aim to recognise, reduce and ultimately remove misconceptions that the students and pre-service teachers may already hold and prevent further misconceptions from developing. All the topics with identified misconceptions (Appendix 33) will not be addressed due to time constraints, the focus will be placed on Photosynthesis. It is expected that the intervention programme will help develop the pre-service teachers’ cognitive ability and improve their thinking skills and in turn have a positive impact on the students they teach.

3.9: Summary and Conclusion
This chapter identified what a misconception was, how they are formed and the implications they can have on the learner (Burgoon et al 2011; Crowther and Price 2014). It was noted that many teachers are unaware or underestimate the effects of misconceptions on students learning. Students will not be able to advance in their understanding of a concept without tackling their misconceptions (Mak et al 1999; McComas 2005). Therefore teachers need to provide opportunities for students to argue and debate their concepts (Simon et al 2006). It was well documented that these opportunities aren’t a regular occurrence as teachers are pressured to teach towards the exam and are not required to have formal structured time to tease out and discuss difficult concepts leading to teachers being the centrepiece of instruction with students left as passive learners in the classroom (Bahar et al 1999; McComass 2005; O’Grady et al 2014). Teachers need to promote conceptual change within their classrooms but if they are to do it effectively need the support and guidance of schools, university partnerships and policy makers as they place a strong hold on teachers instruction in the classroom (Galvin
et al 2015). How are teachers supposed to implement this without the education, knowledge and support? (Lehane et al 2013).

A number of effective teaching strategies were cited in the literature at promoting conceptual change in the classroom; however strict guidelines need to be followed to prevent them being counterproductive (Mayo 2001). Why students find the learning of Biology difficult was explored in detail and international and national studies were examined to add further depth to understanding (Capa 2000). The attitudes of teachers, their subject matter knowledge, time constraints, inaccurate explanations, lack of practical and engaging resources and the overloaded nature of the Biology syllabus were found to significantly affect the way students learned their Biology (Bahar et al 1999; Haambokoma 2007). In particular, if a teacher isn’t happy and knowledgeable in his/her career they won’t be able to instil an interest in their students or be able to challenge students’ conceptual understanding. This needs to be taken into account when evaluating the intervention programme that no one teacher is the same all will implement instruction differently.

Learning is a complex phenomenon, where previous beliefs and understandings have a significant impact (Treagust and Duit 2009). The teacher is one of the most influential characters on students learning, which can have both positive and negative effects which are highlighted in the literature. The classical approach to conceptual change and tackling misconceptions was one of replacement and elimination, more recent research have noted that students in fact have to restructure their pre-instructural structures which is a slow and gradual process as misconceptions are firmly held and deeply rooted (Vosniadou 2008; 2012). Researchers of students’ conceptions and conceptual change have conceptualised learning as being embedded in various theoretical frameworks with epistemological,
ontological and affective orientations (Duit and Treagust 2009; Taber 2006; Taber 2012). Teachers need to have good subject matter knowledge for students to engage in this process effectively. The constructivist view of learning has its strengths when implementing conceptual change however, it needs to be used in the classroom with great care as students’ attempts to understand new knowledge themselves could cause the development of further misconceptions (Hare and Graber 2007). Promoting a positive and engaging learning environment can be a difficult process for teachers to develop due to many constraints such as; curriculum setters, accountability and performance, material overload and lack of time (Darling Hammond 1998; Hattie 2013). In addition, it is important that teachers are aware that students could be at different stages of cognition and so it is important to introduce concrete concepts to students before abstract ones to cater for all learners in the classroom.

Didactic teaching is certainly perceived as an outdated approach in the literature however science teaching in Ireland has been traditionally very didactic and in some cases continues to be so (Forfás 1999). Teachers need structures to be put in place so they can recognise and restructure their own misconceptions. It is well documented that teaching involves a lot more than cognition; it involves the social environment, culture, values and interests of the students as well (Biesta and Miedema 2002). Pre-service teachers and teachers were found to successfully develop and implement inquiry based classrooms when supported and mentored by experts in the field, instead of being “spoon-fed” the information teachers were provided with opportunities for active discussion and collaboration where they were responsible for their own learning (Lehane et al 2013). It can be very difficult for teachers to fulfil this role as a teacher when their teacher education training doesn’t address it. It has been well documented that there is a
significant gap between theory and practice (Mooney Simmie and Lang 2013). A number of different effective teaching strategies have been explored (analogies, concept cartoons, conceptual change text, concept maps, digital resources, inquiry approaches, models and reflective practices) and will form part of this intervention.

There is a need for new and innovative efforts in relation to the continuing education of all teachers (Abell 2008; Luera et al 2005; Sullivan-Watts et al 2013). Effective and evidence-informed pedagogic practices are clearly required by all teachers, and students, to identify, overcome and eliminate misconceptions in the acquisition of accurate scientific knowledge. One way of improving the quality of teachers in this regard can be achieved by targeting pre-service teachers, ensuring that they have capacity to continually interrogate their misconceptions, while working alongside peers and teacher educators to recognise and reduce, if not completely remove, Biology misconceptions. This will pose challenges to all teacher educators and policymakers (Aikenhead 2001; Galvin et al 2015; O’Grady et al 2014).

Examples of successful intervention programmes have also been discussed. This project aims to create a valuable intervention programme to help teachers recognise misconceptions that their students may have and provide them with the strategies, knowledge and support that can be used in the classroom to recognise, reduce and remove misconceptions already held and prevent further misconceptions from developing. The literature from this review will shape the development and implementation of this intervention placing particular emphasis on misconceptions in photosynthesis, senior cycle students’ learning, teaching and pedagogy, continual professional development and the implications school culture and policy makers have on them.
Chapter 4: Materials and Methods

4.1: Introduction

This chapter outlines the methods used for the collection and analysis of results for phase one, two and three of the project. It includes a description of each of the sample groups and an explanation on how the diagnostic instruments and intervention programmes were developed, administered and analysed. The validity and reliability of the diagnostic tests used throughout the three phases are analysed along with the ethical considerations and limitations of the study.

4.2: Research Design

The research design of a project provides the overall structure to the study, bringing all the elements of the research together (Leedy and Ormrod 2005). When designing the research the author must take the research questions of the project into account and the collection of different types and interpretation of data. The practical issues of the project must be considered, such as data availability, collection and interpretation, timeframes and ethical issues (Booth et al 2008). The author identified that there was a lack of research carried out in Ireland in relation to misconceptions in Biology. This issue has been the main focus of this project. In order to investigate this topic a variety of data from different sources were needed. The author decided that in order to obtain the best results possible a mixed method approach would best serve the requirements of the project.

4.3: The Mixed Method Approach

The mixed method approach is where the researcher combines both quantitative and qualitative research techniques, methods and concepts within the one investigation (Johnson and Onwuegbuzie 2004). This approach offers the researcher more choices in
how the project is designed, but also in what methods to use for data collection, analysis and interpretation (Snape and Spencer 2003). The combination of the two methods can help the researcher to better understand the area being explored (Neill 2007). The goal of the mixed method is not to replace either approaches but to draw each on each of their strengths while reducing the weaknesses. While both quantitative and qualitative approaches were used in this project, the quantitative approach was more dominant with the qualitative approach adding a greater sense of depth and scope to the overall picture. One of the main reasons the author chose a mixed method approach for this investigation was that it ensures triangulation of the data (Johnson and Onwuegbuzie 2004). Triangulation refers to using a number of observers, sources of data and methods (Denzin 1970; Olsen 2004). Triangulation is believed to help deepen and widen the authors understanding of the study (Olsen 2004). In addition, it is thought to increase the validity of the data obtained as it helps to reduce bias (Anderson and Arsenault 1999).
Phase 1:
- The identification of misconceptions in Biology that students, pre-service and qualified teachers possess.
- The identification of misconceptions in Irish Biology textbooks.

Phase 2:
- Development and implementation of additional pedagogy module.
- Evaluation of module.
- Design and development of website.

Phase 3:
- Design and development of teaching pack to help improve conceptual understanding in the classroom.
- Evaluate the effectiveness of the teaching strategies and resources implemented.

Figure 4.1 Breakdown of the phases of the Research Project
4.4: Phases of the Research Project

Figure 4.1 outlines the three phases of this study. Phase 1 was the initial phase, the results of which informed Phases 2 and 3. These phases will be outlined in further detail in the subsequent sections.

4.5: Phase One: The Identification of Misconceptions in Biology that Students and Teachers possess

This phase of the project aimed to identify the Biology topics that had the most prevalent misconceptions in Irish second level students as well as their teachers. A detailed and extensive literature review was carried out to determine misconceptions in Biology that are internationally recognised. Detailed descriptions of the misconceptions for each Biology topic are presented in (Appendix 33). From the literature, the Biology topics which held the most misconceptions were; Photosynthesis, Respiration, Circulatory system, Genetics and Ecology. These topics account for a large percentage of the Leaving Certificate Biology syllabus (approximately 37%). In addition to the literature reviewed, the author examined four senior cycle Biology textbooks along with 2 revision textbooks. As a result of the significant increase in the sale of revision books (The Irish Times 2011). The books were examined page by page by the author and the oversimplification and inaccurate information that were identified were reviewed by Biology specialists, in the particular topic of Biology being analysed. The identified text and representations that could contribute to the formation of misconceptions in the Irish textbooks examined can be found in Table 3.2 of chapter 3.

4.5.1: Research Questions

Based on the review of the literature, the following research questions were identified

5. To what extent do senior cycle students, pre-service and qualified teachers hold misconceptions in Biology and what misconceptions are the most prevalent?
6. How can conceptual change be incorporated effectively in the Science classroom?
7. What implications does conceptual change have on the design of curricula and instruction?
8. What challenges does school culture present for learning, teaching and continual professional development?

4.5.2: Development of a Detailed Identification Instrument

Following on from a preliminary study (carried out by the author in 2011/12) a detailed identification instrument was further developed in order to determine the type and level of misconceptions held by teachers and students. The instrument consisted of a paper and pencil survey. It was developed with the assistance of Biology specialists in the specific areas. A number of draft versions of the identification instrument were reviewed by the project supervisor and experts in the relevant fields of Biology. Any modifications noted by these experts were reviewed and adjusted accordingly.

A paper and pencil survey was used as it has been found to be the most appropriate and effective method to use in a classroom based setting (Al Khawaldeh and Al Olaimat 2010; Mak et al 1999; Schmelzing et al 2012; Yenilmez and Tekkaya 2006). The students were given 20 minutes to complete the survey during a single Biology lesson. The survey consisted of two sections A and B. Section A of the survey was related to the personal information of the participants; both senior cycle students and qualified Biology teachers. The additional information differed between the sample groups.

Gender, age, level at which the student is studying senior cycle Biology and the level the student was previously studying at junior cycle, grade obtained in junior cycle Science and type of school were collected in order to determine if any of these factors had a significant effect on the number of misconceptions the student may hold in relation to the topics
examined. Similarly, years of service was collected from the teachers to determine if teachers with more years of experience have less misconceptions or vice versa.

Section B was designed to determine the number of misconceptions present among the participants in areas of Biology that held the most prevalent misconceptions. This section consisted of twenty questions. The amount of time required to answer each question was considered when allocating the overall time to complete the identification instrument. The level of difficulty of the questions and the appropriate use of language were also considered. The survey consisted of six different types of questions; traditional multiple choice questions, multiple choice questions with two answers (two tier multiple choice), true or false statements, correct statements (A or B), open ended questions, labelling and identification questions.

Table 4.1 Types of questions included in the Identification Instrument

<table>
<thead>
<tr>
<th>Type of Question</th>
<th>Description of Question</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traditional multiple choice question</td>
<td>Different styles of multiple-choice style questions were employed throughout the Identification Instrument including 'stem questions'. These were used most often where the stem of the question presented a statement, a problem to be solved or question to be answered. This was then followed by possible answers to choose from in relation to this survey there were 4-5 answers. Within the choice of responses there was the correct answer, the identified misconception and distracters. In an attempt to further validate the results of the Identification Instrument there was an option included; I don’t know the answer. Including this option aimed at reducing inaccuracies of the study due to blind guessing by pupils when they had no awareness or comprehension of the answer.</td>
</tr>
<tr>
<td>Two tier multiple choice question</td>
<td>Tiered multiple choice questions is where you’re asked the first question in the first part and you’re asked to explain your reason for giving that answer in the second part, these type of questions are better indicators of thorough understanding.</td>
</tr>
<tr>
<td>True or false statements</td>
<td>True or false statements are when a participant is presented with a statement and is asked to circle if the statement is true or false.</td>
</tr>
<tr>
<td>Correct statements (A or B)</td>
<td>In the correct statement questions the participant is presented with two statements one in a column labelled A and the other statement in a column labelled B and is asked to circle the correct statement in each row by choosing statement A or B.</td>
</tr>
<tr>
<td>Open ended questions</td>
<td>These questions required participants to explain phenomena in their own words.</td>
</tr>
<tr>
<td>Labelling &amp; identifying questions</td>
<td>These types of questions are when the participant is asked to label the heart for example or identify which part of the plant the arrow is pointing at.</td>
</tr>
</tbody>
</table>
Following ethical approval, a pilot study was carried out by administering the identification instrument to one school to examine the validation of the questions and to see if any improvements could be made before administering the instrument to all the other schools. Cohen et al.(2007) argues the purpose of piloting surveys for many reasons. The main reasons are as follows:

- To check the clarity of the questions, instruction and layout of the identification instrument.
- To check the time it took to complete the identification instrument.
- To identify any questions on the identification instrument that may cause confusion.

Informal Interviews were also carried out with six students and two teachers after the administration of the instrument in order to get feedback. As a result of this feedback minor changes were made to the wording of questions to improve the clarity of the question being asked. Piloting increases the validity and reliability of the questions being asked and makes sure they are suitably designed for the specific sample audience. It also ensures that the reliability and accuracy of the results obtained will not be jeopardised after the relevant data has been collected (Bell 2005). The identification instrument was finally reviewed by a statistician from to ensure their competency for analysis.

Table 4.2 Structure of the Identification instrument and the source of the question that tested that individual misconception

<table>
<thead>
<tr>
<th>Concept Area</th>
<th>Question No.</th>
<th>Concept being tested</th>
<th>Source that identified Misconception</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photosynthesis</td>
<td>Q2, Q4, Q8,</td>
<td>Misconceptions relating to what type of organisms carry out Photosynthesis, the reactants and products of Photosynthesis, what parts of the plant carry out Photosynthesis.</td>
<td>(Barman et al 2003; Kose 2008; Marmoroti and Galanopoulou 2006)</td>
</tr>
<tr>
<td></td>
<td>Q11.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Respiration</td>
<td>Q2.</td>
<td>Misconceptions relating to what type of organisms carry out respiration, when they carry it out, why plants carry respiration.</td>
<td>(Bahar et al 1999; Martlew and Connolly 1996)</td>
</tr>
</tbody>
</table>
### 4.5.3: Distribution of Identification Instrument

The instrument was distributed to Leaving Certificate students studying Biology and their teachers. For the distribution of the instrument, there were two main methods of recruiting volunteers. The principals of the schools were recruited by means of a letter (Appendix 5) and were invited in this letter to take part in the study. Alternatively, the principal or Biology teacher was contacted directly. A list of second level schools offering Biology was obtained from the Department of Education and Science. The author ensured that when recruiting the schools for the study that the sample groups were taken from the different types of schools in the Irish Education system. At present there are three different types of schools in Ireland (the percentage of each type of school is indicated in the brackets).

- Voluntary Secondary schools (53.6% Male: 14.9%, Female: 19.9%, Mixed: 65.2%)
- Vocational Schools (33.7%)
Community and Comprehensive schools (12.3%)

Forty seven second level schools received the surveys to distribute to Leaving Certificate Biology students and their qualified Biology teacher. The surveys were distributed in May 2013 along with information about the research (Appendices 10, 11, 12, 13 & 14). The schools were asked to complete the permission forms (Appendices 6, 7 & 8) along with the survey (Appendix 16) and to email the author when they were completed so the author could arrange a suitable time to collect them from the school. The month of May was identified as a suitable time to distribute the surveys as at this time in the year students would have completed the course and studied all the topics examined in the survey.

4.5.4: Description of Sample Groups from Secondary Schools

The following is a description of the sample groups used in Phase 1 of the study from secondary schools. A summary of the number of surveys completed by the Leaving Certificate students and their qualified Biology teachers in the different types of schools can be seen in Table 4.3.

Table 4.3 Summary of the types of schools that completed the survey

<table>
<thead>
<tr>
<th>School Type</th>
<th>No. of students who completed survey</th>
<th>No. of qualified teachers who completed survey (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voluntary Secondary Schools</td>
<td>n = 471 (~48%)</td>
<td>n = 13 (~37%)</td>
</tr>
<tr>
<td>Vocational Schools</td>
<td>n = 201 (~20%)</td>
<td>n = 9 (~26%)</td>
</tr>
<tr>
<td>Community and Comprehensive schools</td>
<td>n = 319 (~31%)</td>
<td>n = 13 (~37%)</td>
</tr>
</tbody>
</table>
Table 4.4 The breakdown of the number of Leaving Certificate Biology students and qualified Biology teachers involved in this study according to gender and age

<table>
<thead>
<tr>
<th>Age profile</th>
<th>Leaving Certificate Biology students</th>
<th>Qualified Biology teachers</th>
</tr>
</thead>
<tbody>
<tr>
<td>16 years old</td>
<td>129 (~14%)</td>
<td>N/A</td>
</tr>
<tr>
<td>17 years old</td>
<td>551 (~58%)</td>
<td>N/A</td>
</tr>
<tr>
<td>18 years old</td>
<td>272 (~29%)</td>
<td>N/A</td>
</tr>
<tr>
<td>Total number of responses</td>
<td>n = 952 Missing = 39</td>
<td>n = 34 Missing = 1</td>
</tr>
<tr>
<td>Number of Male responses (valid % of groups)</td>
<td>n = 463 (~47%)</td>
<td>n = 15 (~44%)</td>
</tr>
<tr>
<td>Number of Female responses (valid % of groups)</td>
<td>n = 528 (~53%)</td>
<td>n = 19 (~56%)</td>
</tr>
</tbody>
</table>

4.5.5: Introduction of Identification Instrument into Pre-service Pedagogy Modules

The next stage of Phase 1 involved distributing the survey to the pre-service pedagogy modules in the teacher training colleges around Ireland with the aim of determining the misconceptions held by student teachers. The course directors of the Science teaching programmes were contacted by an email (Appendix 15) requesting their students’ participation. Participants were given until December 2013 to complete the surveys. However, only one teacher training college returned completed surveys and consent forms (Appendix 9) as the other teacher training colleges that were approached were weighed down at the time with completing surveys from other research projects.

Table 4.5 Description of the teacher training college that took part in the study

<table>
<thead>
<tr>
<th>Name of degree</th>
<th>University of Limerick (N = 53)</th>
<th>University of Limerick (N = 40)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year of study</td>
<td>Second year</td>
<td>Third year</td>
</tr>
<tr>
<td>Gender profile</td>
<td>Male = 38 (~39%)</td>
<td>Female = 55 (~59%)</td>
</tr>
<tr>
<td>Age profile</td>
<td>19 years = 28 (~30%)</td>
<td>20 years and over = 9 (~10%)</td>
</tr>
<tr>
<td></td>
<td>Missing = 56 (~60%)</td>
<td>Missing = 56 (~56%)</td>
</tr>
</tbody>
</table>
4.5.6: Data Collection

Postal surveys are usually the best type for a large scale study such as this. Although some schools received the surveys in person visiting all schools individually, particularly for such a large number, was neither practical nor realistic. Because of this a number of techniques were used in order to improve the response rate of the survey. These included:

- giving the Biology teachers instructions for answering the questions
- using language that was simplified and easy to understand
- providing schools with a posted envelope and address to return the surveys to or a phone number to contact for the author to arrange to collect them

4.5.7: Analysing the Results from the Identification Instrument

The survey was firstly coded and was then inputted accordingly into SPSS statistics 20. The values for the codes were labelled using the variable view of the SPSS programme. All responses to the survey were coded including the open ended questions. The individual responses to each question on the survey were analysed and the areas that held the highest number of misconceptions amongst the participants were identified. The analysis involved the data being depicted using graphical representations such as frequency Tables and bar charts. Cross tabulations and box plots were also used. The analysis involved determining if any of the following variables; gender, age, level of study, grade obtained, type of school, year of study and years of service had an impact on the number of misconceptions a participant held. A descriptive statistics frequency distribution was carried out to identify the percentage of Leaving Certificate students, pre-service teachers and qualified teachers that held misconceptions. A descriptive statistics frequency distribution was also performed on the variables listed above. Cross tabulation was used to show the overall performance (mean % of misconceptions and mean % of correct responses) of each group in relation to each individual question from the
identification instrument. The data was also analysed to explicate whether differences existed between the types of participants on a number of levels through cross-tabulation function in SPSS. Tests for normality were performed on all three groups to see if the data collected was normally distributed. If the sample sizes were \( \geq 50 \) the Kolmogorov-smirnov value was used and if the sample size was \( < 50 \) the Shapiro-Wilk value was used. A significant value \( P \geq 0.05 \) indicated the data was normally distributed. If the groups were found to be normally distributed a one-way Anova was used and if they weren’t normally distributed the Kruskal-Wallis test was used. The Kruskal-Wallis test is a nonparametric test used to compare three or more populations. The Mann-Whitney U-Test is a nonparametric test used for comparing two populations. The Mann-Whitney U-Test was used to identify if there was a link between the mean percentage of correct responses and mean percentage of misconceptions with gender. If the \( P \)-value was found to be \( < 0.05 \) it indicated that there was a statistically significant difference between the groups being analysed. A correlation test was performed between the years of service and the mean misconceptions held and mean correct responses obtained, if normally distributed the Pearson’s Chi-squared test was used and if not normally distributed the Spearman correlation test was used (Field 2013). The \( p \)-value reveals whether the relationship or correlation between the variables is significantly sound. This correlation was also used for Phase 2 and 3 of this project.

4.6: Phase Two: Development of an Additional Pedagogy Module and Website Resource

4.6.1: Introduction

After an analysis of the literature and the results obtained from the identification instrument in phase one it was proposed to develop an intervention programme that would help teachers identify and overcome their misconceptions and their student’s
misconceptions. The intervention programme consisted of a module on misconceptions, implementation and examination of the teaching strategies identified in the literature and a development of a website resource on misconceptions in Biology. The intervention programme made up phase 2 and 3 of the project.

4.6.2: Additional Pedagogy Module

An voluntary additional pedagogy module was introduced to the University of Limerick that focused on identifying and overcoming misconceptions, as teachers are given the role to identify and overcome misconceptions in the classroom without ever being given advice or resources in their teacher education programmes on how to address them (Asay and Orgill 2010). In this way teachers gain greater exposure to learners' misconceptions (and opportunities to reflect on their own concepts) in order to realise the importance of this area of practice. The identification of misconceptions in Biology is essential for misunderstandings to be addressed and for learning to be developed and advanced (Hodgson and Pyle 2010). Effective and evidence-informed teaching strategies are needed by the teachers to identify, overcome and eliminate misconceptions in the Biology classroom (Galvin and O'Grady 2014). As the author is based in the University of Limerick, the third year pre-service Biology teachers were chosen to deliver the module to as they were going on their teaching practice the following semester (September 2014). The author was given a time frame of 6 weeks to deliver the module outside of scheduled class time. One particular Biology topic was focused on throughout the module but examples were given on how they could incorporate it in different topics. The module was delivered over six 1 hour lectures. The pre-service teachers received a copy of the module being taught as well as worksheets and class activities. The headings of the lectures were

✓ What are misconceptions?
✓ How are misconceptions developed?
How can misconceptions be identified in the classroom?
Teaching strategies that help to overcome and eliminate misconceptions
Accessing literature on misconceptions
Common misconceptions in Biology

When choosing a research sample there are four vital factors to be considered: the size of the sample, the representativeness of the sample, access to the sample and the sampling strategy used (Cohen et al 2007). A sample size of \( n = 63 \) third year pre-service teachers took the additional module. As it was highlighted in the literature that teachers contribute greatly to the formation of misconceptions amongst students (Barrass 1984; Dikmenli 2010; Donovan and Bransford 2005; Flores et al 2003; Garnett et al 1995; Hashweh 1987; Kose 2008; Sanders 1993; Soyibo 1995; Yip 1998a; Yip 2001) it is important that teachers in their initial teacher training programs are made aware of misconceptions and given the necessary skills and resources to help identify, overcome and eliminate them from the classroom.

4.6.3: Organisation of Suitable Class Time and Classroom

The supervisor of this project was also the course director of the Biological Sciences concurrent teaching degree, so an informal meeting was organised to discuss the most suitable days and times to run this additional module. An email was sent to the laboratory technician in charge of timetabling the labs to see if it was possible to be in a laboratory for the class as there would be more space and greater opportunities for carrying out experiments. Unfortunately this could not be catered for and so a classroom had to suffice.

Table 4.6 Description of sample group that completed the Additional Pedagogy Module

<table>
<thead>
<tr>
<th>Males</th>
<th>Females</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>n= 25 (~40%)</td>
<td>n= 38 (~60%)</td>
<td>n= 63 (100%)</td>
</tr>
</tbody>
</table>
4.7: Development of Evaluation Form for Pre-service Teachers

In order to evaluate how beneficial the module was to the pre-service teachers, an evaluation form (Appendix 19) was designed for them to complete after the module was delivered. The author looked at a variety of evaluation templates used by lecturers to evaluate their own modules. This helped the author to design an informed evaluation questionnaire for the module. The evaluation form consisted of eight questions; of both open and close ended questions. The open ended questions sought to explore the pre-service teachers’ opinions and thoughts on the module delivered. While the close ended questions provided quantitative data. Two scaled questions were used where the respondents were asked to indicate their level of agreement with the statement. The likert scale questions used in this questionnaire were based on a scale that ranged from ‘strongly agree’ to ‘strongly disagree’ for one question and for the other question ‘excellent’ to unsatisfactory’. At the end of the last lecture pre-service teachers were given fifteen minutes to complete the evaluation form. The data from the questionnaire was inputted into SPSS and coded accordingly. The results obtained from the questionnaire are represented in the results chapter of this project.

4.7.1: The Rational and Aims of the Evaluation Form

The evaluation form was designed in order to gain the opinion of the pre-service teachers of the additional pedagogy module. The main aims of the evaluation were:

- To get an insight into their overall opinion of the module, the main strengths and how the module could be improved.
- To gain an insight into their feelings in relation to reflective practice and the need for the topic of misconceptions to be incorporated into teacher training colleges.
To identify what they have learned about misconceptions from the module and if they plan to incorporate what they have learned in their fourth year teaching practice placement.

Table 4.7 Description of sample group that completed Evaluation Form

<table>
<thead>
<tr>
<th></th>
<th>Males</th>
<th>Females</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>n= 20 (~39%)</td>
<td>n= 31 (~61%)</td>
<td>n= 51 (100%)</td>
</tr>
</tbody>
</table>

4.7.2: Analysis of Data gathered from Evaluation of Module

The data gathered from evaluating the module involved both quantitative and qualitative data. The quantitative data was inputted into SPSS and analysed using descriptive frequencies and cross tabulations with certain sets of data. A Cronbach’s Alpha was used to test the reliability of the evaluation form. A value of 0.749 was achieved. Any value that lies between 0.7 and 0.8 indicates good reliability according to (Jiang et al 2000). In relation to the qualitative data collected, it was first transcribed into separate word documents. The author thoroughly read the transcripts and made notes on the significant and interesting points that arose. The data was then categorised into themes; this is commonly done when analysing qualitative data (Bryman 2004) to help reduce the vast amount of data obtained. The themes were chosen while keeping the research questions in mind. A critical friend was used at this stage to ensure the author was consistent throughout and to reduce author bias. Any remaining data outside of the main themes were discussed individually as additional information to support relevant arguments, see results and analysis phase two, chapter 6. However, given the differential power relations involved between this researcher, the course director and the students taking this pedagogy module the results have to be cautiously interpreted as only indicative of effectiveness of the module, rather than as definitive findings (Apple 2012).
4.8: Selection of Topic to be focused on in this Intervention Programme

Photosynthesis was chosen as it is a prevalent Biology topic that upper secondary school students find conceptually challenging. It is one of the most active areas of research on Biology misconceptions (Ekici et al 2007). Students commonly find this topic difficult due to its abstract concepts and develop a wide range of misconceptions. Despite the fact that Photosynthesis is a fundamental topic in Science syllabi, research has shown that students often have a poor understanding of it (Anderson et al 1990; Çepni et al 2006; Ekici et al 2007; Kose 2008; Özay and Özas 2003). The process of Photosynthesis plays an important role in the understanding of many aspects of living systems. Furthermore, this process is essential in the cycling of matter and energy flow through ecosystems (Anderson et al 1990, Eisen and Stavy 1988). Finally, the topic Photosynthesis is taught at primary, second and third level of education. An analysis was performed on how often this topic is examined in the Leaving Certificate Biology exam and it was found that from 2004 to 2013 Photosynthesis has appeared every year in the higher level paper and 9 out of the 10 years in the ordinary level papers examined (State Examinations Commission 2013).

4.9: Design and Development of Website Resource

It has been noted in the literature and recorded in the results from the identification instrument that both pre-service and qualified teachers hold misconceptions. It is essential that both groups are given assistance in identifying and overcoming them. It was easier to reach pre-service teachers as they are still in their teacher training colleges, however it was more difficult to get the information to teachers already out in schools. Therefore, the author decided to develop a website on misconceptions in Biology. The author met with an expert in the field of website design and together they drew up a draft template of the author’s ideas. A number of concept designs were discussed and trialled.
4.10: Website Content

The website (http://www.elainegalvin.ie/) consists of literature on Biology misconceptions, resources relating to the Biology syllabus and state examinations commission, teaching strategies to identify and overcome misconceptions, example lesson plans and frameworks, the module delivered to pre-service teachers, a blog, and an option for teachers to upload their own resources. The sub-headings displayed on the website are explained in more detail below. The website also requires a log in to access so the author can keep account of its users.

4.10.1: Literature

This section comprises of literature that relates to research into investigating misconceptions, the importance of subject matter knowledge, teaching and learning specific to Science and innovation in Science. Teachers need to be provided with relevant reading in order to understand the best way to approach their classroom (Darling-Hammond and Bransford 2007).

4.10.2: Teaching Strategies

A number of different teaching strategies have been suggested by researchers over the past few years that help identify and overcome misconceptions and promote conceptual change. These include; analogies (Clement and Brown 2004), concept maps (Broggy and McClelland 2008), concept cartoons (Ekici et al 2007), conceptual change texts (Mikkila-Erdmann 2001), models (Ross et al 2010), demonstrations and experiments (Tippett 2010), digital media resources (McLellan 2007), Science reflective journals (Towndrow 2008) and the inquiry based approach method. Relevant research on these methods can be found in this section of the website and examples of these methods can be explored throughout the example lesson plans.
4.10.3: Biology Syllabus

It is essential for both pre-service teachers and qualified teachers to be aware of how the material they are teaching is assessed therefore information from the state examinations commission in relation to the Biology exam has also been uploaded to the site. It includes class tests by topic, marking schemes and exam papers from 2004 to 2014, three chief examiners reports, definitions and general information on the Biology syllabus. It also makes suggestions for cross curricular links and provides a guide for lab organisation and safety.

4.10.4: Lesson Plans and Frameworks

The lesson plans and frameworks on the website were developed by third year pre-service teachers in the University of Limerick who completed the additional pedagogy module. The pre-service teachers have incorporated the strategies and resources they learned into their lesson plan design. Lesson plans and frameworks can be searched by topic.

4.10.5: Misconceptions

This section includes misconceptions that researchers have found to be prevalent among students and teachers in the various topics on the Leaving Certificate Biology syllabus. This is a convenient resource for teachers to visit prior to teaching a lesson. The misconceptions are grouped by topic.

4.10.6: Add Resources

There is an option for users to upload a resource which they found or created themselves which they found useful to tackle misconceptions. This allows teachers to share their resources with one another and promotes a collaborative approach to teaching.
4.11: Phase Three: Implementation of Teaching Strategies learned in Module

Phase three was the final stage of the research. From carrying out the voluntary additional pedagogy module with the pre-service teachers in phase 2, it was evident that the pre-service teachers weren’t familiar with the suggested teaching strategies in the literature and that they were not implemented in today’s classrooms. Teachers were either unaware of the strategies that they could implement or were underestimating the effects of misconceptions on their students’ learning. The pre-service teachers felt that prior to the additional pedagogy module that they didn’t give their students enough opportunities in their lesson to discuss, argue or explain what they learned and what they were still unsure about. They felt from observing their cooperating teachers on second year teaching practice that this situation wasn’t uncommon. It was decided to assess if the teaching strategies explored by the pre-service teachers in the module would have a positive effect on students’ conceptual understanding of Photosynthesis.

4.11.1: Recruitment of Pre-service Teachers to implement the Lesson Guides

At the end of third year the pre-service teachers were assigned their fourth year teaching practice schools. Pre-service teachers were recruited via email (Appendix 20). An email was sent to all the third year pre-service teachers that completed the additional pedagogy module. They were asked if they wanted to get involved in further research and if so, were they given a Senior Cycle Biology class for their fourth year teaching practice. Fourteen pre-service teachers were assigned to the intervention after determining their timetables, the types of the schools they were going to be teaching in and their second year teaching practice grade. Pre-service teachers were paired according to their type of school and their grade on second year teaching practice to reduce any variables.
4.11.2: Description of Sample Group

Seven of the teachers taught their students using strategies and resources which they learned from the additional pedagogy module while the other seven teachers taught their students using traditional teaching methods using a didactic approach. The students that were taught by the teachers using strategies and resources from the module were called the experiment groups and the students taught by the teachers that used traditional teaching methods were called the control groups. There were 14 secondary schools, 14 pre-service teachers and 14 fourth year class groups that took part in the study. Table 4.9 outlines the general cohort involved in the study.

Table 4.9 Description of the sample group involved in implementation of lesson guides

<table>
<thead>
<tr>
<th>Teacher Pair</th>
<th>Experiment Group</th>
<th>Control Group</th>
<th>Type of School</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pair A</td>
<td>n= 25</td>
<td>n= 25</td>
<td>Community School</td>
</tr>
<tr>
<td>Pair B</td>
<td>n= 24</td>
<td>n= 26</td>
<td>Comprehensive School</td>
</tr>
<tr>
<td>Pair C</td>
<td>n= 24</td>
<td>n= 27</td>
<td>Voluntary Secondary School</td>
</tr>
<tr>
<td>Pair D</td>
<td>n= 27</td>
<td>n= 24</td>
<td>Voluntary Secondary School</td>
</tr>
<tr>
<td>Pair E</td>
<td>n= 26</td>
<td>n= 24</td>
<td>Vocational School</td>
</tr>
<tr>
<td>Pair F</td>
<td>n= 25</td>
<td>n= 28</td>
<td>Voluntary Secondary School</td>
</tr>
<tr>
<td>Pair G</td>
<td>n= 22</td>
<td>n= 21</td>
<td>Voluntary Secondary School</td>
</tr>
</tbody>
</table>

4.11.3: Development of Pre and Post test on Misconceptions in Photosynthesis

It was not possible to assess the misconceptions held about every Biology topic in this study, therefore, the topic of Photosynthesis was selected to examine, for the reasons mentioned in section 4.8.1. On analysis of previous studies carried out in relation to misconceptions in Photosynthesis in phase 2 it was possible to develop a list of common misconceptions that students possess about Photosynthesis. The most common misconceptions that exist in this area of Biology are noted on Table 3.22 in chapter three. Questions that would test if Irish students held these misconceptions were identified and
developed. The Test Instrument (Appendix 21) was made up of three parts. Part one of the instrument was comprised of thirteen two-tier multiple choice questions all of which had an option to choose of “I don’t know” to eliminate guessing. Two-tier multiple-choice items appear to provide a feasible approach for evaluating students’ understanding, and for identifying commonly held misconceptions (Haslam and Treagust 1987; Odom and Barrow 2006; Peterson et al 1989). The items in two tier multiple choice diagnostic instruments are specifically designed to identify students’ misconceptions and misunderstandings in a limited content area. The first part of each item consists of a multiple-choice content question having two or three choices. The second part of each item contains possible reasons for the answer to the first part. Part two required the students to draw and label a diagram to explain Photosynthesis in plants. This part was included as some students find it easier to diagrammatically represent understanding of Photosynthesis. The third section consisted of ten short answer open-ended questions. By contrast to the two tier multiple choice questions, open-ended questions allows the author to explore each student’s reasoning patterns and supporting conceptions (Voska and Heikkinen 2000). The way in which the questions were designed needed to vary as how a question is designed and structured can affect the way the student answers the question. Therefore, it is important to rule out that the style of question had any effect on the overall performance of the student in the test instrument. There are many approaches discussed in chapter three that can be used to identify misconceptions amongst students. Of these many approaches, interviews, and multiple-choice diagnostic tests are the most common methodologies and have acquired strong support as a viable approach (Abdullah and Scaife 1997; Adeniyi 1985; Dikmenli 2010; Osborne and Gilbert 1980; Peterson et al 1989; Schmidt 1997).
4.11.4: Lesson Guides and Resources for Experiment Group and Control Group

The author created a booklet (Appendix 22) to provide the pre-service teachers with lesson guides that would help identify and overcome misconceptions in relation to Photosynthesis in plants. The lesson guides in this booklet were based on students’ learning from the Junior Certificate Science curriculum. It was aimed at developing students’ conceptual understanding of this curriculum and building on pre-existing knowledge. Transition Year is designed to act as a bridge between Junior Certificate and Leaving Certificate and to enhance students’ independent self-directed learning skills that are required for the Leaving Certificate syllabus. The objective of these lesson guides was to tackle misconceptions in the classroom and to help students further develop their skills associated with problem solving, communication, teamwork and research. This booklet introduced teaching strategies into the classroom which have been found to help improve students’ conceptual understanding of topics, for example; models, Science reflective journals, conceptual change text, concept cartoons, experiments, concept maps and demonstrations. The booklet was structured around a Transition Year class that was scheduled to have one single and one double Biology class per week. The booklet consisted of seven lesson guides; each lesson guide contains the objectives of the lesson, activities to implement during the lesson, possible questions that could be asked by the teacher, follow up activities and resources required to implement each activity. Objectives were chosen for the lesson using Blooms Taxonomy to ensure that cognitive, affective and psychomotor skills were being addressed in every lesson where possible (see Appendix 22 for booklet containing lesson guides, resources and PowerPoints). The author focused on identifying and overcoming misconceptions in relation to where Photosynthesis occurs in a plant, where a plant gets its energy for Photosynthesis, where a plant gets its carbon and the relationship between Cellular Respiration and Photosynthesis. The author met the
seven pre-service teachers that were implementing the lessons to the experiment group for a two hour tutorial to go through the running of the lessons. Pre-service teachers left the tutorial with all the resources they needed to implement their lessons. The control group met separately. They were all asked to work from the same Biology textbook when delivering their lessons and to implement the activities/experiments stated in the textbook for Photosynthesis. The book they used was “Leaving Certificate Biology” by Michael O’ Callaghan. The teachers were asked to take a didactic approach to their teaching.

4.11.5: Distribution of Test Instrument
The author met with the fourteen pre-service teachers involved in the implementation of the intervention programme prior to their teaching practice placement for a short meeting. The author went through the test instrument with the pre-service teachers so they would be able to answer any question that arose during administration of it. The author gave a sealed envelope of the pre-test instrument to each of the pre-service teachers with stamped addressed envelopes to return to the author once completed by their class group. A list of instructions was also included in the envelope to ensure smooth and accurate delivery of the test instrument. The test instruments were distributed to the fourth year Biology class groups in late September 2014. The post test was then distributed to the experiment and control groups two to three weeks after the lesson plans were completed and returned to the author in the University of Limerick (December 2014).

4.11.6: Introduction of Website Resource to Pre-service and Qualified Teachers
Prior to the pre-service teachers going on their teaching practice placement the author met with them for a tutorial on how to navigate through the website. The other three years of pre-service Science teachers in the University of Limerick were also introduced to the website during their Science pedagogy lectures. The author delivered an informal
workshop to the qualified teachers on the website in seven of the schools participating in the study.

4.11.7: Evaluation of the Intervention Programme

The main aims of the intervention programme were to provide teachers with the necessary skills, knowledge, resources and support structure to recognise and reduce misconceptions in Biology and to see an improvement in their students’ conceptual understanding as a result. At the very beginning of the pre-service teachers’ teaching practice, the students were given the pre-test instrument to identify the misconceptions in Photosynthesis held by the students. Students in the experiment group were then taught by pre-service teachers using the teaching methods and resources aimed at aiding conceptual change and overcoming misconceptions. The control group were taught the same topic but with traditional teaching methods. The scores of the experiment groups’ post-test scores were compared with the control groups’ test-scores. The experiment groups and control groups individual pre and post test scores were also examined to determine if conceptual change strategies can help to improve the students’ conceptual understanding of difficult concepts and help overcome misconceptions that could be deeply rooted.

4.11.8: Interviews with Pre-service Teachers

When the pre-service teachers finished their teaching practice placement the author met with them to discuss their experiences of their teaching for the ten weeks. The pre-service teachers’ reflection of their teaching intervention was the basis of their individual interviews. The pre-service teachers were firstly provided with an information sheet (Appendix 23) on the interview and a consent form (Appendix 24) to sign once they had made their decision. The interviews were conducted individually and were all recorded. The interviews (Appendix 25) took a semi-structured approach where there were questions
that the author asked but leading questions may vary depending on the pre-service
teachers’ responses. Pre-service teachers were also asked questions on their content
knowledge in relation to Photosynthesis to see if this affected their students’ performance.

4.11.9: Measurement of the Effectiveness of the Website Resource

The effectiveness of the website resource was measured in three ways; by the number of
registered users, through an interview with pre-service teachers and the completion of an
evaluation of the website. With reference to the interview one of the questions posed to
the pre-service teachers that implemented the lesson guides was the usefulness of the
website resource. The responses from this question were recorded and discussed in phase
three of the results, chapter 7. A likert scale evaluation form (Appendix 26) was designed
and distributed via email to all the qualified teachers and pre-service teachers that
registered and used the website that the author had access to. A likert scale was chosen as
teachers and pre-service teachers were asked to complete this evaluation the last week of
school before Christmas holidays. Teachers and schools were very busy at this time so it
was recommended that a short likert scale evaluation would be completed to a higher
standard than an open response type evaluation at this busy point in time. The evaluation
forms were distributed and collected to the teachers in question on the same day.

4.11.10: Analysis of pre and post Identification Test

Both the experiment group and control group completed the same pre-test on
Photosynthesis misconceptions. An independent t-test was performed on the data to see if
there was any significant difference between the control and experiment groups with
respect to previous understanding of Photosynthesis prior to implementation of the lesson
guides. Each pair of teachers taught their group the same topic but the teacher teaching the
experiment group was given a lesson guide to follow and resources to use to help identify
and overcome misconceptions. The control group received traditional Science instruction, teaching strategies that included teacher explanation and textbooks with no consideration of students’ misconceptions. After completion of the lessons both the experiment group and the control group completed the same post-test on Photosynthesis misconceptions two to three weeks after all the lessons had been implemented. For Part 1 (i.e. the two tier multiple choice questions), the students’ responses were marked according to the marking schemes provided by Haslam and Treagust (1987) (Appendix 27). One mark was awarded for each correct response and both the first and second-tier answers had to be correct in order to be awarded with a mark. The maximum total score was thirteen while the minimum total score was zero. To compare between the two groups, the differences in the mean scores of each group were analysed using the independent t-test. To analyse the students’ responses on each question in Part 1, the percentages of students for each response were analysed using the chi-squared test. For part 2, the assessment scheme used by Kose (2008) (Appendix 28); the students’ drawings on Photosynthesis were categorised into Levels 1–4. To compare the students’ responses between the intervention and the control groups, the percentage of students’ answers categorised for each level were analysed using the chi-square test.

For Part 3 (i.e. short answer questions) a marking scheme was constructed based on the paper by Eisen and Stavy (1988), and also from the students’ responses to each question (Appendix 29). A mark was awarded for each correct answer as suggested in the marking scheme. To compare the students’ responses between the experiment and the control groups, the pre-tests and post-tests total scores and the mean scores for each question were analysed using the independent t-test. The effectiveness of the teaching strategies used to overcome misconceptions were examined through a series of tests and the data obtained was tabulated in chapter 7.
4.11.1: Analysis of Data received from Pre-service Teachers’ Interviews

The data obtained from the seven pre-service teachers interviewed after the implementation of the lesson guides were transcribed from the audio tape and themed in the same way as the data from the evaluation form was themed. A critical friend was used to reduce bias when selecting the themes from the data obtained. A similar thematic content analysis (Anderson 1998) procedure was followed:

- Multiple copies of the interview transcripts were made including post interview notes.
- The transcripts were typed and saved on a word file coded as Teacher A, B etc.
- A highlighter was used to identify the descriptions that were relevant to the topic of inquiry.
- The highlighted key words and phrases were placed in separate files that were categorised according to the questions being asked.
- The categories were revised regularly while coding the data.
- The entire data was read and grouped accordingly, and regrouped as appropriate.
- After a few days, the original interview transcripts were reread both by the author and a critical friend without looking at the groupings or categories.
- The author added, removed, relabelled, regrouped and categorised where needed with the help of the critical friend.
- Categories that were too large were reduced and subdivided and categories that were too small were looked upon again in the original transcripts.
- The groupings/categories were looked over as a whole to ensure they highlighted the areas that were under investigation.
- After a few days, the author reread the total categories as a whole. Considered whether the categories made overall sense of the interview transcripts given the topic and the themes were formed.

(Anderson 1998; Anderson 2004; Creswell 1998)

4.12.1: Validity of this Study

There were various measurements taken in this study to ensure validity of the study. A mixed method approach of gathering the data was used in this study. The data was collected using a variety of sources; surveys, evaluations and interviews. The use of such a wide variety across the three phases of the research adds to the validity of the study. The author has analysed the data rigorously; used a critical friend when analysing transcripts
from interviews and has obtained advice from experts in relation to the design, implementation and analysis of instruments used throughout the three phases. With reference to the generalisability of the results, this study can be applicable to the international community in relation to misconceptions in Biology and teaching and learning. The data was collected from a broad range of sources; the second level schools were randomly chosen from a list made out by the Department of Education and pre-service Science teachers from different Science backgrounds were surveyed. Where possible, the validity of the research instruments used in phase one, two and three were tested using construct validity. Construct validity can be determined using correlation coefficient. The correlation coefficient relates to the strength of relationships between variables (Balnaves and Caputi 2001). Correlations ranging between 0.65-0.85 are said to be accurate (Cohen et al 2006). The correlation between question 1 and 8 of the evaluation form prove that group predictions, for the research instrument in phase two can be made accurately as the correlation coefficient was found to be 0.796.

Table 4.10 Correlation coefficient between phase two respondents to question 1 and 8 of the evaluation form

<table>
<thead>
<tr>
<th>Question 1: What was your overall impression of the module?</th>
<th>Question 8: I will use the teaching strategies/resources presented in this module on my fourth year teaching practice.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pearson Correlation coefficient=0.796</strong></td>
<td></td>
</tr>
</tbody>
</table>

Validity can be further enhanced and strengthened by the careful structuring of questions and piloting instruments where possible, to allow adjustments to be made before distributing to the entire cohort. In this study both identification instruments (phase one and three) were piloted in advance of use, the evaluation form and interview questions were reviewed by experts in the particular fields prior to administration. The validity of
the interview questions and assigning of themes from the data was enhanced by a critical friend.

4.12.2: Reliability of this Study

The purpose of reliability of the data is to ensure that if this investigation was repeated by another investigator it would be expected they would receive similar data with a high correlation. To ensure reliability was achieved throughout the investigation a number of strategies were used. A large sample size was used; 991 Senior cycle secondary school students, 93 pre-service teachers and 35 qualified Biology teachers were surveyed in phase one of the investigation. The identification instrument for phase one of the investigations was found to be relatively unreliable (0.546) according to the Cronbach’s alpha statistical test, possibly due to the range of questions within one instrument. Cronbach’s alpha is a statistical test, which examines how well items on a scale correlate with one another (Field 2009). Therefore, in phase two the evaluation form was carefully designed and reviewed thoroughly prior to administration. A Cronbach alpha score of 0.749 was achieved. Any value that lies between 0.7 and 0.8 indicates good reliability according to (Jiang et al 2000). Scales in the pre and post instruments in phase three of the study received a Cronbach alpha score of 0.889, indicating good reliability. It is much more difficult to ensure reliability with qualitative data. In order to minimise error in the qualitative data; semi-structured interviews were carried out with the pre-service teachers in phase three of the study. Triangulation ensures that the data is received from a number of different participants in varied manners. This allows the data obtained to be confirmed or challenged by the different methodologies used (Bell 2005). In this study data was obtained from students, pre-service and qualified teachers. Both qualitative and quantitative methods of analysing the data were used and the data was analysed using a variety of theoretical perspectives. Triangulation in this study ensured the author of
statistically and emotionally evaluating the presence and effect of misconceptions among the participants involved in the study.

4.12.3: Confidentiality

The researcher maintained confidentiality and anonymity at all times; no identifiable information was recorded or documented. The surveys that were distributed to students, pre-service and qualified teachers in phase one were stored under lock and key in the supervisor’s office and all computer systems were password protected which can only be accessed by the researcher and supervisor. A coding system was in place for teachers interviewed in phase 3 for example teacher 1, teacher 2. In relation to the experiment and control groups of students in phase 3 that were taught Photosynthesis they were coded using “C” for control group and “E” for experiment group. Again, any transcribed notes from interviews were stored away under lock and key in the supervisor’s office and password protected.

4.13: Ethical Considerations

Ethics approval was sought and received for all phases of this research investigation. The ethical procedures outlined by the University of Limerick were followed in the collection and use of the data obtained. Ethical issues that arose during the application process were the issues of child protection and informed consent when administrating surveys to students under the age of 18 years. For the surveys that were administered to students under the age of 18 parental and school consent from their teacher and acting principal were required before they were sampled. All participant involved in the three phases of the study were given information on the research, consent forms and informed of their ability to withdraw themselves from the study at any time. Similarly, for the interviews pre-service teachers were informed of their consent and what the information they were
providing was being used for. Interviewees were initially contacted via email, then by phone call and then all participants involved attended a tutorial on the research they would be involved in. All interviews were numerically coded for example teacher 1, 2 etc.

4.14: Limitations of the Study

4.14.1: The Identification Instrument in Phase One

In phase one of the investigation the identification instrument used to assess students’, pre-service and qualified teachers’ misconceptions didn’t include for all questions an option of “I don’t know the answer”. Providing this option for each question would reduce the number of participants guessing their response and identify for the researcher that the participant if they held a misconception or if they just didn’t know the material. In relation to administration of the identification instrument a time constraint of 20 minutes was placed on all participants who completed the instrument. However, it was not possible for the investigator to be present for the administration of the identification instrument due to the variety of locations where it was completed. Therefore in all cases this time constraint cannot be guaranteed. Some participants may have had a reduced or extended amount of time to consider the concepts presented in the instrument.

4.14.2: Scale of the Study

The method of the research merely provides a snapshot of the misconceptions held by the students assessed at a particular period of time. It cannot be guaranteed that these results provide an accurate view of all Irish Leaving Certificate students studying Leaving Certificate Biology. In assessing Leaving Certificate students, pre-service teachers and qualified teachers the objective was to expose the level of change in conceptual understanding of Biology from Leaving Certificate level to the qualified teacher. A more
accurate method of research would be to follow the same group of participants across a three year cycle to facilitate the observation of a true level of change.

4.14.3: Recruitment of Pre-service Teachers

For phase three of the investigation it was very difficult to recruit pre-service teachers to implement the lesson guides of Photosynthesis. Some of the main reasons were;

- They weren’t given their class timetable until after the summer.
- Some schools assigned the topics they had to teach during their ten week placement.
- They had two different groups of TY’s over the ten week placement.
- They didn’t feel confident in their own subject matter knowledge to teach it during their ten week placement.

4.14.4: Time and Financial Constraints

During the three phases of the research investigation time and financial constraints were an issue. It would have been beneficial to interview students that still deeply held misconceptions after the lesson guides were implemented to see where they were still getting confused. However, the surveys were kept confidential and so there was no way of knowing which individual students still held misconceptions. In addition, interviews are very time consuming and fourth year is a very busy year for students as they undergo a number of extracurricular activities. In relation to evaluating the website resource teachers in the schools were very busy and pre-service teachers had just finished their placement and were going off campus for a month for their Christmas holidays therefore, a likert scale evaluation form was distributed. Deeper understanding of the usefulness of the website resource would have been obtained from an open ended evaluation but the author had to appreciate that it was a busy time of the year for both pre-service and qualified teachers.
Chapter 5: Results and Analysis of Phase 1

5.1: Introduction

The results of the data analysis from phase one are presented in this chapter. The focus of the chapter is to address the first research question outlined in Chapter 4; Section 4.6.1.

- To what extent do senior cycle students, pre-service and qualified teachers hold misconceptions in Biology and what misconceptions are the most prevalent?

The quantitative data collected in Section B of the identification instrument is presented. This facilitates the identification of the presence or absence of misconceptions in Biology in the second level students, pre-service teachers and qualified teachers examined. Statistical analysis was carried out on the data collected from Section A to identify if there is a link between the percentage of misconceptions or the percentage of correct responses obtained in relation to the particular group of participants (senior cycle students, pre-service teachers, qualified teachers), gender, age, Leaving Certificate level, Junior Certificate level, grades obtained at Junior Certificate Science and Leaving Certificate Biology, type of school attending, year of study and years of service. This data is represented from Section 5.2 to 5.8. Section B of the identification instrument consisted of 8 biological topics; Photosynthesis, Respiration, Ecology, Diffusion, the Circulatory system, Genetics and DNA, the Cell cycle and Plant and Animal Reproduction. A breakdown of participants' performance in relation to the individual concepts analysed are presented in Section 5.9 to 5.17. Prevalent trends are noted among the Biology topics examined.
5.2: Overall Performance of Senior cycle students, Pre-service Teachers and Qualified Teachers in relation to Section B of the Identification Instrument

The multiple choice questions in section B consisted of common misconceptions, correct responses and distractor answers. The open ended questions were categorised into misconceptions, correct responses and ‘other’. Table 5.1 shows the overall performance of the participants (represented as the mean % of misconceptions held and the mean % of correct responses obtained).

Table 5.1 Overall performance (percentage of correct responses and percentage of misconceptions held) of the groups (Senior cycle students, Pre-service teachers and Qualified teachers) in relation to Section B of the diagnostic test. Significance was tested with a one-way Anova; there was a highly significant difference between the performance of the three groups P<0.001.

<table>
<thead>
<tr>
<th>Group</th>
<th>Mean % of misconceptions held</th>
<th>Mean % of correct responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Senior cycle Students (n=991)</td>
<td>35.13% ± 1.118</td>
<td>56.80% ± 0.265</td>
</tr>
<tr>
<td>Pre-service teachers (n=93)</td>
<td>24.23% ± 0.435</td>
<td>68.59 % ± 1.10</td>
</tr>
<tr>
<td>Qualified teachers (n=35)</td>
<td>9.72% ± .646</td>
<td>86.68% ± 1.77</td>
</tr>
<tr>
<td>Significance</td>
<td></td>
<td>P&lt;0.001</td>
</tr>
</tbody>
</table>

The mean percentage of misconceptions held by senior cycle students was 35.13% signifying a serious concern. Studies carried out in the area of misconceptions in Biology are thus far limited. No similar study in relation to identifying Irish senior cycle students’ misconceptions in Biology was identified in the extensive review of the available literature, however small scale studies carried out in the University of Limerick showed similar results to this study.

The mean percentage of misconceptions held by the pre-service teachers was 24.23%. This was a notable improvement of 10.9% from the mean percentage of misconceptions held by senior cycle students; however this was still a considerably high percentage of
misconceptions held for pre-service teachers in their second and third year of teacher education. All of the questions asked were linked directly to topics on the Leaving Certificate Biology syllabus, suggesting that these pre-service teachers may serve as direct agents for propagating and reinforcing the misconceptions to their students. Although there is limited literature on pre-service teachers a similar study was found in relation to Chinese novice (first year of teaching) teachers where it was found that only 50% of participants received an overall score of over 42% (correct responses) (Yip 1998). The mean percentage of misconceptions the qualified teachers held was 9.72%. Again, this was a notable improvement of 14.51% from the mean percentage of misconceptions held by pre-service teachers and an improvement of 25.41% when compared to the senior cycle students, but still indisputably high.

A one-way Anova was conducted to compare the means of the overall performances of the three groups. Results (Table 5.1) show that there is a highly significant difference (P<0.001) between the performance in the three groups. This is further emphasised in the box plots Figure 5.1 and 5.2.
Figure 5.1 Box plot of the median percentage of misconceptions held by the three groups examined.

The box plot shows the difference in performance among the three groups. The median value is much higher for the students than the pre-service teachers and lowest for the qualified teachers. The three outliers towards the bottom of the chart indicate that three students held fewer misconceptions than the students examined and the outlier at the very top of the chart indicates that one student held more misconceptions than the students examined (Field 2013).
Figure 5.2 Box plot of the median percentage of correct responses held among the three groups examined

From the box plot it is evident that the qualified teachers have a much higher median value in relation to the percentage of correct responses than the pre-service teachers and the students. The median for correct responses is higher for all three groups compared to the median for misconceptions. There are mild outliers present in both the data obtained from the students and the pre-service teachers similar to Figure 5.1 however in this plot there are also two extreme outliers indicated with the stars among the pre-service. This highlights that two pre-service teachers among the group were found to have far less correct responses than the other pre-service teachers examined.

5.3: Link between Gender and Performance

A Mann-Whitney U Test compared the mean percentage of correct responses and mean percentage of misconceptions with gender. Results show that there was no significant
difference (P=0.458) between gender and the percentage of correct responses. There was also no significant difference (P=0.521) found between gender and the number of misconceptions held (Table 5.2). Interestingly, females tend to achieve higher grades than males from primary to third level in subject examinations but don’t outperform males on aptitude tests; as females are found to be more self-disciplined but not necessarily have a better conceptual understanding (Duckworth and Seligman 2006; State Examinations Commission 2010; State Examinations Commission 2013).

Table 5.2 Link between Gender and performance (percentage of correct responses and percentage of misconceptions held) in the identification instrument across the three groups (Senior cycle students, Pre-service teachers and Qualified teachers). Significance was tested using a Mann-Whitney U test; no significant difference was observed.

<table>
<thead>
<tr>
<th>Gender</th>
<th>No. of sample (%)</th>
<th>Mean % misconceptions</th>
<th>Mean % of correct responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female</td>
<td>602 (~54%)</td>
<td>33.31% ± .369</td>
<td>58.66% ± .675</td>
</tr>
<tr>
<td>Male</td>
<td>515 (~46%)</td>
<td>33.72% ± .405</td>
<td>58.80% ± .492</td>
</tr>
<tr>
<td>Significance</td>
<td>Correct responses P=0.458; Misconceptions P=0.521</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5.4: Link between Age and performance

There were 5 different age categories ranging from 16 years to 20 years and over. Analysis was only carried out on the students and the pre-service teachers as the qualified teachers weren’t asked to specify their age in the diagnostic test. A one-way Anova comparing the mean percentage of correct responses and mean percentage of misconceptions with age showed that there was no significant difference (P=0.084) between age and the percentage of correct responses. Similarly, there was no significant difference (P=0.397) between age and the percentage of misconceptions (Table 5.3).

Table 5.3 Link between Age and performance (percentage of correct responses and percentage of misconceptions held) in Section B of the identification instrument across the three groups (Senior cycle students, Pre-service teachers and Qualified teachers). Significance was tested using a one-way Anova; no significant difference was observed.
<table>
<thead>
<tr>
<th>Age</th>
<th>No. of sample (%)</th>
<th>Mean % misconceptions</th>
<th>Mean % of correct responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>16 years</td>
<td>129 (11.91%)</td>
<td>36.12%</td>
<td>55.27%</td>
</tr>
<tr>
<td>17 years</td>
<td>550 (50.78%)</td>
<td>35.28%</td>
<td>56.75%</td>
</tr>
<tr>
<td>18 years</td>
<td>272 (25.12%)</td>
<td>35.04%</td>
<td>57.23%</td>
</tr>
<tr>
<td>19 years</td>
<td>28 (2.59%)</td>
<td>37.28%</td>
<td>54.25%</td>
</tr>
<tr>
<td>20 years and over</td>
<td>9 (0.83%)</td>
<td>35.92%</td>
<td>56.95%</td>
</tr>
<tr>
<td>Missing</td>
<td>95 (8.77%)</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Significance: Correct responses P=0.084; Misconceptions P=0.397

Figures 5.3 and 5.4 further emphasise the findings obtained from the analysis. The median for all categories is between 30% and 40% in relation to the box plot on percentage of misconceptions held highlighting that there is little difference between the age categories. Mild outliers are present among the 17 year old and 19 year old age categories indicating that one person from the 17 year old age category held more misconceptions than the other participants in the category, similarly one person from the 19 year old age category held more misconceptions. Three people in the 17 year old age category held fewer misconceptions than the other participants in the category.
Figure 5.3 Box plot of the median percentage of misconceptions held among the different age categories

The median across all 5 age categories in Figure 5.4 lies between 50% and 60% further highlighting that there is little difference between the percentages of correct responses among the different age categories. A few mild outliers are observed in both the 17 years and 18 years old categories indicating that students or pre-service teachers within this age category have more correct responses or much less correct responses than the other participants in the category.
There have been direct links found between age and cognitive development (Piaget 1970); however, movement of students from concrete to formal operational is not set to any particular age (Woolfolk et al 2008). In this study, however, there was no statistically significant difference found between age and misconceptions.

5.5: Link between Level at which Participant Studied and Performance

Senior cycle students and pre-service teachers were asked to identify at what level they studied junior cycle Science and senior cycle Biology. For both junior and senior cycle examinations there are two levels of papers that students can sit ordinary level or higher level where ordinary level is conceptually less challenging than higher. In relation to junior cycle Science a one-way Anova compared the mean percentage of misconceptions and the mean percentage of correct responses held by the student with the level they studied.
studied. Results indicate that there was a highly significant difference (P=0.001) between level studied and percentage of misconceptions. There was also a highly statistically significant difference (P<0.001) between level studied and percentage of correct responses. Participants that studied at higher level had fewer misconceptions and a greater percentage of correct responses than participants that studied at Ordinary level (Table 5.4).

**Table 5.4 Link between level (higher or ordinary) at which participant studied Junior and Senior examinations and performance (percentage of correct responses and percentage of misconceptions held). Significance was tested using a one-way Anova; a highly significant difference between level studied and performance was found at both Junior and Senior level examinations.**

<table>
<thead>
<tr>
<th>Groups</th>
<th>Junior Certificate level</th>
<th>Mean % misconceptions</th>
<th>Mean % of correct responses</th>
<th>Leaving Certificate level</th>
<th>Mean % misconceptions</th>
<th>Mean % of correct responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leaving Certificate students and pre-service teachers</td>
<td>Higher = 819 Ordinary = 88</td>
<td>Higher = 33.75</td>
<td>Higher = 58.43</td>
<td>Higher = 990</td>
<td>Higher = 33.98</td>
<td>Higher = 58.14</td>
</tr>
<tr>
<td>Significance</td>
<td></td>
<td>Ordinary = 36.91</td>
<td>Ordinary = 54.73</td>
<td>Ordinary = 91</td>
<td>Ordinary = 37.06</td>
<td>Ordinary = 54.36</td>
</tr>
</tbody>
</table>

Similarly, at Leaving Certificate level, there was a highly statistically significant difference (P <0.001) found between level studied and overall performance (mean % of misconceptions and mean % of correct responses). This confirmed the assumption that students taking the higher level examination at either Junior or Leaving Certificate level hold fewer misconceptions than students sitting the ordinary level paper as students taking the ordinary level exam would typically find the topics more conceptually challenging (Chi and Roscoe 2002; State Examinations Commission 2013).

5.6: **Link between Grades obtained in Junior and Senior Cycle Examination and Performance**

In Section A of the identification instrument students and pre-service teachers were asked to identify the grade they obtained in their junior cycle Science exam and senior cycle
Biology exam to identify if there was any link between the grade obtained in terminal examinations and the percentage of misconceptions or percentage of correct responses. A one-way Anova compared the mean percentage of misconceptions and correct responses with the grade obtained, results indicated that there was a statistically significant difference (P<0.001) between the grade obtained in the junior cycle Science exam and the overall performance of the participant. The higher the grade they obtained the fewer the misconceptions they held and the greater percentage of correct responses they obtained.

In relation to senior cycle level, there was no significant difference (P=0.466) between percentage of misconceptions held and grade obtained. There was also no statistical significant difference (P=0.081) between percentage of correct responses and the grade achieved (Table 5.5). Overall, this is a worrying trend which suggests that Irish senior cycle students have an insufficient understanding of Biological concepts. This is despite the high level of honours grades achieved by senior cycle Biology students where the percentage of students achieving an honours grade (A, B or C) from 2006 to 2013 remained consistently above 70% (State Examinations Commission 2006-2013). These grades would seem to suggest a good level of understanding of Biological concepts, which is greatly in contrast with the findings of this study. Although the results of this study cannot be confirmed to conform to the remainder of senior cycle students, it suggests that the model of testing used to assess senior cycle Biology students does not accurately display their level of understanding. This has been confirmed throughout the literature where senior cycle examinations are associated with the regurgitation of facts as opposed to understanding of information (Hennessy et al 2011; Gleeson 2012). In addition a recent study investigated past and present senior cycle Biology examination papers using Bloom’s Taxonomy and found that over 90% of the questions on the paper were from the lower levels of Bloom’s Taxonomy which is predominantly the recall of knowledge
This study suggests that the junior cycle examination tests more understanding than information and facts, although there hasn’t been any research carried out on the levels of questions used on the junior cycle examination, the revised syllabus was updated in 2008 with greater emphasis on understanding and using an inquiry based approach in the classroom (NCCA 2008) whereas the senior cycle Biology syllabus hasn’t been reviewed or updated since 2002 (NCCA 2002).

Table 5.5 Link between Grade (A, B, C, D, E) obtained in the Junior or Senior level examination and performance (percentage of correct responses and percentage of misconceptions held) in the diagnostic test. Significance was tested using a one-way Anova; the grade obtained at Junior level showed a highly significant difference in relation to performance while the grade obtained in the Senior cycle was not found to be significant to overall performance.

<table>
<thead>
<tr>
<th>Grades</th>
<th>Grade in Junior Certificate Science</th>
<th>Mean % misconceptions</th>
<th>Mean % of correct responses</th>
<th>Grade in Leaving Certificate Biology</th>
<th>Mean % misconceptions</th>
<th>Mean % of correct responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>117</td>
<td>26.91%</td>
<td>65.01%</td>
<td>A = 48</td>
<td>21.08%</td>
<td>72.61%</td>
</tr>
<tr>
<td>B</td>
<td>217</td>
<td>33.40%</td>
<td>58.76%</td>
<td>B = 36</td>
<td>22.74%</td>
<td>69.22%</td>
</tr>
<tr>
<td>C</td>
<td>143</td>
<td>36.91%</td>
<td>55.74%</td>
<td>C = 1</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>D</td>
<td>27</td>
<td>38.02%</td>
<td>54.14%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>1</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Significance:
- Junior level= correct responses and misconceptions P<0.001;
- Senior level=correct response P=0.466 and misconceptions P=0.081

5.7: Link between the Type of School Students Attended and their Performance

Senior cycle students were examined from three types of schools; voluntary secondary schools, vocational schools and comprehensive/community schools. A one-way Anova compared the mean percentage of misconceptions and mean percentage of correct responses with the school attended. Results showed there was no significant difference (P=0.343) found between school attended and the percentage of misconceptions. In contrast, there was a significant difference found (P=0.045) between school attended and
the percentage of correct responses (Table 5.6). Students that attended a Voluntary secondary school held a higher percentage of correct responses. Interestingly this type of school is the highest “feeder school” of undergraduates into the University of Limerick every year. Voluntary secondary schools also continue to have the highest retention rates at both junior cycle and senior cycle stages (Department of Education and Skills 2010).

Table 5.6 Link between type of school (Voluntary secondary school, Vocational school, Comprehensive/Community school) attended and performance (percentage of correct responses and percentage of misconceptions held) in the diagnostic test. Significance was tested using a one-way Anova.

<table>
<thead>
<tr>
<th>Type of school</th>
<th>No. of students</th>
<th>Mean % of misconceptions</th>
<th>Mean % of correct responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voluntary secondary school</td>
<td>484</td>
<td>34.27%</td>
<td>58.04%</td>
</tr>
<tr>
<td>Vocational school</td>
<td>209</td>
<td>34.77%</td>
<td>56.82%</td>
</tr>
<tr>
<td>Comprehensive/Community school</td>
<td>332</td>
<td>34.74%</td>
<td>57.64%</td>
</tr>
<tr>
<td>Significance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Correct responses P=0.045; Misconceptions P=0.343</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5.8: Link between Year of Study and Performance

In this investigation, two undergraduate groups (Year 2 and Year 3 pre-service teachers) were examined. A one-way Anova was used to compare the mean percentage of misconceptions and mean percentage of correct responses with the year of study of the participant. The results indicated that there was a significant difference (P=0.006) between the percentage of misconceptions held and the year of study. The students in year 3 of study held fewer misconceptions than the second years. There was also a significant difference (P=0.002) between the year of study and the percentage of correct responses, where the third year pre-service teachers performed better (Table 5.7). This result indicates that pre-service teachers have encountered and overcome some of their misconceptions between second year and third year; possible contributors could be
additional pedagogy modules and teaching practice during the second semester of second year. Similar findings were noted in the literature that over time, students had more experience and time to develop and accept the scientifically correct concepts (Birk and Kurtz 1999).

Table 5.7 Link between year of study (second or third) as pre-service teacher and performance (percentage of correct responses and percentage of misconceptions held). Significance was tested using a one-way Anova; there was a significance difference observed for both the percentage of correct responses and misconceptions held.

<table>
<thead>
<tr>
<th>Year of Study</th>
<th>No. of pre-service teachers</th>
<th>Mean % of misconceptions</th>
<th>Mean % of correct responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Second year</td>
<td>n = 53</td>
<td>23.81%</td>
<td>68.24%</td>
</tr>
<tr>
<td>Third year</td>
<td>n = 40</td>
<td>19.57%</td>
<td>73.85%</td>
</tr>
<tr>
<td>Significance</td>
<td>Correct responses P=0.002; Misconceptions P=0.006</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5.9: Relationship between Years of Service as a Qualified Teacher and Performance

Thirty five qualified teachers participated in this investigation, the mean years of service was 12.37 years. A Spearman correlation test was used to identify if there was any association between years of service and performance in the diagnostic test. The results indicated that there was no significant relationship (P=0.885) between percentage of misconceptions and years of service. There was also no significant relationship (P=0.954) found between percentage of correct responses and years of service. Figure 5.4 further emphasises the results obtained from analysing the data.
Figure 5.5 Relationship between years of service and percentage of misconceptions held

It is evident from the graph that the relationship was found to be nonlinear. In this study, there was no significant difference between the years of service and the misconceptions held. However, other studies have found the more experience a teacher has the better their subject matter knowledge (Kind 2009).

5.10: Quantity of Misconceptions held by the Participants

The twenty questions included in the current study incorporated 45 misconceptions cited from the literature (Appendix 33). Twenty one of these misconceptions were found to be indisputably present (≥30% of the population of Leaving Certificate students tested believing them to be true). The remainder of the misconceptions tested (twenty four) were
found to be held by the students where they ranged from 0.11 to 29% of the population tested.

Thirteen of the 45 misconceptions were found to be held by ≥30% of the population of pre-service teachers. Almost all of the remaining misconceptions (thirty) were held in the range of 1.09 to 29.21% of the population of pre-service teachers. Although the trend is undoubtedly more positive than that observed for Leaving Certificate students, it draws into question the success of teacher education in terms of subject expertise. Third level teacher education should go above and beyond the level of subject knowledge required for the Leaving Certificate in order to make pre-service teachers experts within their subject area. However, the findings of this study suggest that teacher education is currently unsuccessful in achieving a good level of conceptual knowledge. Having participated in three years out of a four year Biology education degree course, participants would be expected to display a higher level of Biological competency than what was observed. It is in the nature of misconceptions to be resistant to change; this has been well documented (Department of Jobs, Enterprise and Innovation 2011; Khalid 2003; Smith et al 1994). Misconceptions will not be overcome by traditional teaching methods (Cakir 2008; Kendeou and Van den Broek 2008). This suggests that third level teacher education in Ireland is currently not encouraging the alteration of Biological misconceptions, most likely existing in students from their second level education.

Two of the 45 misconceptions were found to be held by ≥30% of the population of qualified teachers. A further twenty six misconceptions were held in the range of 2.86 and 29.41% of the population of qualified teachers. Yip (1998a) also confirmed that qualified teachers demonstrated similar conceptual problems inferred from their misconceptions. These preliminary results indicate that misconceptions are resistant to change (Smith et
al 1993; Sundberg 2003) and they persist from each level of education to the next (Kapyla et al 2009; Krall et al 2009; Novak 1987; Partosa et al 2013; Yip 2007).

5.11: Performance of Participants in relation to Photosynthesis

The concepts examined in relation to Photosynthesis were; the type of organisms that carry out Photosynthesis, the reactants and products of Photosynthesis and the parts of the plant that carry out Photosynthesis. Questions 2, 4, 8 and 11 examined these concepts (Appendix 15). The main trends identified from analysing the data showed that although the mean percentage of misconceptions was highest among the students, both the pre-service teachers and qualified teachers still held misconceptions in all four questions examined. In addition, the pre-service teachers held fewer misconceptions than qualified teachers for two parts of question 2 (Table 5.8-5.11).

Table 5.8 Performance of participants in relation to Question 2 parts; a, c, e and g

<table>
<thead>
<tr>
<th>Question</th>
<th>Leaving Certificate students</th>
<th>Pre-service teachers</th>
<th>Qualified teachers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q2 a)</td>
<td>% Misconception = 56.01</td>
<td>% Misconception = 14.29</td>
<td>% Misconception = 8.57</td>
</tr>
<tr>
<td></td>
<td>% Correct = 43.99</td>
<td>% Correct = 85.71</td>
<td>% Correct = 91.43</td>
</tr>
<tr>
<td>Q2 c)</td>
<td>% Misconception = 72.28</td>
<td>% Misconception = 27.78</td>
<td>% Misconception = 58.82</td>
</tr>
<tr>
<td></td>
<td>% Correct = 27.62</td>
<td>% Correct = 72.22</td>
<td>% Correct = 41.18</td>
</tr>
<tr>
<td>Q2 e)</td>
<td>% Misconception = 13.24</td>
<td>% Misconception = 7.23</td>
<td>% Misconception = 8.57</td>
</tr>
<tr>
<td></td>
<td>% Correct = 86.76</td>
<td>% Correct = 92.77</td>
<td>% Correct = 91.43</td>
</tr>
<tr>
<td>Q2 g)</td>
<td>% Misconception = 73.34</td>
<td>% Misconception = 23.91</td>
<td>% Misconception = 8.57</td>
</tr>
<tr>
<td></td>
<td>% Correct = 26.66</td>
<td>% Correct = 76.09</td>
<td>% Correct = 91.43</td>
</tr>
</tbody>
</table>

The most prevalent misconception found to be present among all three groups of participants was “Plants get their food from the soil via their roots” (Abdullah and Scaife 1997). 43.41% of senior cycle students, 38.04% of pre-service teachers and 2.94% of qualified teachers held this misconception. This indicates a lack of awareness of the process of Photosynthesis which acts as a foundation for all life and energy transfer in
ecological systems. Many students know that plants carry out Photosynthesis but also believe that they must consume “food” which is interpreted as materials such as water, fertilisers, nutrients from the soil (Ebert-May et al. 2003; Marmaroti and Galanopoulou 2006; Ozay and Oztas).

Table 5.9 Performance of participants in relation to Question 4

<table>
<thead>
<tr>
<th>Group</th>
<th>Misconception (food from the soil)</th>
<th>Correct responses (including explanation of the uptake of nutrients, Photosynthesis and dividing cells)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leaving Certificate students</td>
<td>43.41%</td>
<td>56.59%</td>
</tr>
<tr>
<td>Pre-service teachers</td>
<td>38.04%</td>
<td>61.96%</td>
</tr>
<tr>
<td>Qualified teachers</td>
<td>2.94%</td>
<td>97.06%</td>
</tr>
</tbody>
</table>

All three groups examined held the misconception that only the leaves of the plant carry out Photosynthesis, a much lower percentage identified that both the stem and the leaves can carry out Photosynthesis (any green part). 14.52% of the students believed that the roots could carry out Photosynthesis too (Table 5.10). Participants may have developed this misconception from the types of figures and activities used when teaching Photosynthesis. The main diagram that is used when learning about Photosynthesis is one that focuses on the leaves of the plant (Clegg 2011). Common representations used shows Photosynthesis occurring only in the leaves or emphasises the leaves with arrows going in and out of them which could have contributed to the participants thinking that Photosynthesis only occurred in the leaves (Clegg 2011).

Table 5.10 Performance of participants in relation to Question 8

<table>
<thead>
<tr>
<th>Group</th>
<th>Leaf only (misconception)</th>
<th>Leaf and stem (correct response)</th>
<th>Leaf, stem and roots (incorrect)</th>
<th>Other incorrect labelling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leaving Certificate students</td>
<td>76.99%</td>
<td>6.34%</td>
<td>14.52%</td>
<td>2.15%</td>
</tr>
<tr>
<td>Pre-service teachers</td>
<td>60.44%</td>
<td>39.56%</td>
<td>0%</td>
<td>0%</td>
</tr>
</tbody>
</table>
Question 11 (Appendix 15) was in relation to the chemical equation representing Photosynthesis, light was incorrectly represented within the equation. An extremely low percentage of students and pre-service teachers identified the inaccuracy in the representation and less than half (42.86%) of the qualified teachers recognised this (Table 5.11). Textbooks have been found to be a prevalent source that contribute to the formation of misconceptions among students and teachers (Abimbola and Baba 1996; Angell et al 2005; Dikmenli and Cardak 2004; Kose et al 2009). This equation was taken directly from a senior cycle Biology textbook to determine if textbooks could contribute to the formation of misconceptions. An extremely low percentage of students and pre-service teachers identified the inaccuracy in the representation and less than half (42.86%) of the qualified teachers recognised this. Textbooks are usually regarded by educators as a good source of information for teaching students (Abimbola and Baba 1996). However, Science textbooks are continuing to espouse incorrect, outdated and misleading views (Gibson 1996). Teachers who are less competent in subject-matter knowledge may propagate incomplete or erroneous views to their students through inaccurate teaching or uncritical use of textbooks (Sanders 1993). Teachers need to become more effective in using Biology textbooks to promote learning (Kose et al 2009; Yip 1998). Conversely, getting the chemical equation wrong could also be due to poor understanding of chemical formulas and symbols (Yarroch 1985).

<table>
<thead>
<tr>
<th>Group</th>
<th>Correct response</th>
<th>Agreeing because it was balanced</th>
<th>Other incorrect responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leaving Certificate Students</td>
<td>7.99%</td>
<td>80.23%</td>
<td>11.73%</td>
</tr>
<tr>
<td>Pre-service teachers</td>
<td>9.76%</td>
<td>54.88%</td>
<td>35.37%</td>
</tr>
<tr>
<td>Qualified teachers</td>
<td>42.86%</td>
<td>54.29%</td>
<td>2.86%</td>
</tr>
</tbody>
</table>
5.12: Performance of Participants in relation to Cellular Respiration

The concepts studied in relation to Cellular Respiration were the type of organisms that carry out Cellular Respiration, the time of day or night at which they carry it out and why Cellular Respiration is necessary. Question 2 examined these concepts (Appendix 15). In all four parts of the question analysed the senior cycle students held the highest percentage of misconceptions, then pre-service teachers and the qualified teachers held the least. For part b) of question 2 the qualified teachers held no misconception (Table 5.12).

Table 5.12 Performance of participants in relation to Question 2 parts; b, d, f and h

<table>
<thead>
<tr>
<th>Question</th>
<th>Leaving Certificate students</th>
<th>Pre-service teachers</th>
<th>Qualified teachers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q2 b)</td>
<td>% Misconception = 12.91</td>
<td>% Misconception = 8.79</td>
<td>% Misconception = 0</td>
</tr>
<tr>
<td></td>
<td>% Correct = 87.09</td>
<td>% Correct = 91.21</td>
<td>% Correct = 100</td>
</tr>
<tr>
<td>Q2 d)</td>
<td>% Misconception = 44.11</td>
<td>% Misconception = 21.98</td>
<td>% Misconception = 8.57</td>
</tr>
<tr>
<td></td>
<td>% Correct = 55.89</td>
<td>% Correct = 78.02</td>
<td>% Correct = 91.43</td>
</tr>
<tr>
<td>Q2 f)</td>
<td>% Misconception = 43.64</td>
<td>% Misconception = 37.36</td>
<td>% Misconception = 5.71</td>
</tr>
<tr>
<td></td>
<td>% Correct = 56.36</td>
<td>% Correct = 62.64</td>
<td>% Correct = 94.29</td>
</tr>
<tr>
<td>Q2 h)</td>
<td>% Misconception = 71.89</td>
<td>% Misconception = 29.21</td>
<td>% Misconception = 11.43</td>
</tr>
<tr>
<td></td>
<td>% Correct = 28.11</td>
<td>% Correct = 70.79</td>
<td>% Correct = 88.57</td>
</tr>
</tbody>
</table>

Many of the participants did not identify that plants carry out Cellular Respiration. The context in which Cellular Respiration is used may have affected the rate of correct responses. Participants may have confused Respiration which is the act of breathing and intake of oxygen in animals with Cellular Respiration which refers to the process of breaking down glucose to energy (O’Connell 2008).

5.13: Performance of participants in relation to Ecology

The Ecology section of the identification instrument looked at misconceptions relating to whether an organism was autotrophic or heterotrophic, the different types of consumers in a food web/pyramid and factors that affect co-habitation. Questions 3, 5, 6 and 7 (Appendix 15) examined these concepts. Ecological misconceptions are the most
prevalent biological misconceptions that have been identified and analysed (Munson 1994). The main trends identified from the data were that the senior cycle students and pre-service teachers held misconceptions in all four questions examined, however the qualified teachers held no misconceptions in questions 3 and 6. In addition the qualified teachers held a higher percentage of misconceptions to pre-service teachers in question 7 (Table 5.13). Ecological misconceptions appear to emerge after instruction takes place as they are present among all three groups examined which is similar to the findings of other researchers in this area of Biological misconceptions (Khalid 2003; Smith et al 1994).

Table 5.13 Performance of participants in relation to Questions 3, 5, 6 and 7

<table>
<thead>
<tr>
<th>Question</th>
<th>Leaving Certificate students</th>
<th>Pre-service teachers</th>
<th>Qualified teachers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q3 a)</td>
<td>% Correct = 90.93 % Incorrect = 9.07</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>% Misconception = 22.79</td>
<td>% Misconception = 6.90</td>
<td>% Misconception = 0</td>
</tr>
<tr>
<td>Q3 b)</td>
<td>% Correct = 70.50 % Distractors = 6.71</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>% Misconception = 28.73</td>
<td>% Misconception = 6.52</td>
<td>% Misconception = 0</td>
</tr>
<tr>
<td>Q5</td>
<td>% Misconception = 49.90</td>
<td>% Misconception = 46.74</td>
<td>% Misconception = 20.00</td>
</tr>
<tr>
<td></td>
<td>% Correct = 37.83 % Distractors = 12.27</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>% Misconception = 28.73</td>
<td>% Misconception = 6.52</td>
<td>% Misconception = 0</td>
</tr>
<tr>
<td>Q6</td>
<td>% Correct = 57.16 % Distractors = 7.72</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>% Misconception = 28.73</td>
<td>% Misconception = 6.52</td>
<td>% Misconception = 0</td>
</tr>
<tr>
<td></td>
<td>% Didn’t know = 6.39 % Didn’t know = 0</td>
<td>% Didn’t know = 0</td>
<td>% Didn’t know = 0</td>
</tr>
<tr>
<td>Q7</td>
<td>% Misconception = 13.27</td>
<td>% Misconception = 2.17</td>
<td>% Misconception = 2.86</td>
</tr>
<tr>
<td></td>
<td>% Correct = 62.35 % Distractors = 20.20</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>% Misconception = 13.27</td>
<td>% Misconception = 2.17</td>
<td>% Misconception = 2.86</td>
</tr>
</tbody>
</table>

The most prevalent Ecological misconception was identified by question 5 which was in relation to food chains and food webs which was cited from Munson (1991); a food web is interpreted as a simple food chain. 49.90% of senior cycle students, 46.74% of pre-service and 20% of qualified teachers held this misconception. Munson (1994) found this to be a prevalent misconception within his research from 4th grade students to upper-division college students. This lack of basic conceptual understanding in relation to food webs may
have cultivated the other misconceptions uncovered within this topic. The overall results suggest a poor level of conceptual understanding of Ecology in pre-service teachers and students alike. It is possible that these have been proliferated from qualified teachers who also lack conceptual understanding of this topic; this is common according to Burgoon et al (2011). This is made more likely by the fact that these results suggest that teacher education currently does not overcome these misconceptions.

5.14: Performance of Participants in relation to Diffusion

Question 1 (Appendix 15) examined the concept of diffusion; how molecules move from one area to another. The percentage of misconceptions was found to be excessively higher among the students (53.18%) compared to the pre-service (2.35%) and qualified teachers (9.68%). Table 5.14 highlights the performance of the three groups. A similar trend was observed in comparable studies (Marek et al 1994; Odom 1995).

<table>
<thead>
<tr>
<th>Question</th>
<th>Leaving Certificate students</th>
<th>Pre-service teachers</th>
<th>Qualified teachers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1 a)</td>
<td>% Incorrect = 51.26</td>
<td>% Incorrect = 11.63</td>
<td>% Incorrect = 2.94</td>
</tr>
<tr>
<td></td>
<td>% Correct = 48.74</td>
<td>% Correct = 88.37</td>
<td>% Correct = 97.06</td>
</tr>
<tr>
<td>Q1 b)</td>
<td>% Distractors = 27.76</td>
<td>% Distractors = 31.76</td>
<td>% Distractors = 0</td>
</tr>
<tr>
<td></td>
<td>% Correct = 19.06</td>
<td>% Correct = 65.88</td>
<td>% Correct = 90.32</td>
</tr>
<tr>
<td></td>
<td>% Misconception = 53.18</td>
<td>% Misconception = 2.35</td>
<td>% Misconception = 9.68</td>
</tr>
</tbody>
</table>

Concept mapping and conceptual change texts were found to greatly improve second and third level students’ conceptual understanding of diffusion and osmosis (Kose 2007; Tekkaya 2003).

5.15: Performance of Participants in relation to The Circulatory System

The main concepts tested for misconceptions in relation to the Circulatory system were the functions of capillaries, the direction and flow of blood from the heart to the lungs and around the body and why cheeks turn red. Questions 9, 13 and 17 (Appendix 15)
examined these concepts. The main trend found among the data collected (Table 5.15) was again senior cycle students hold a higher percentage of misconceptions compared to the other two groups which is comparable to other studies carried out in relation to second level students (Arnaudin and Mintzes 1985; Sungur et al 2001; Sungur and Tekkeya 2003) and teachers (Barass 1984; Yip 1998). All three groups held misconceptions in the three questions examined except for question 13; pre-service and qualified teachers didn’t hold the misconception where as 44.54% of students did hold the misconception that the right side of the heart brings blood to the right side of the body and the left side of the heart brings blood to the left side of the body only.

Table 5.15 Performance of participants in relation to Questions 9, 13 and 17

<table>
<thead>
<tr>
<th>Question</th>
<th>Leaving Certificate students</th>
<th>Pre-service teachers</th>
<th>Qualified teachers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q9 a)</td>
<td>% Correct = 31.13</td>
<td>% Correct = 50</td>
<td>% Correct = 70.59</td>
</tr>
<tr>
<td></td>
<td>% Misconception = 68.87</td>
<td>% Misconception = 50</td>
<td>% Misconception = 29.41</td>
</tr>
<tr>
<td>Q9 b)</td>
<td>% Correct = 34.48</td>
<td>% Correct = 46.84</td>
<td>% Correct = 78.79</td>
</tr>
<tr>
<td></td>
<td>% Misconception = 65.52</td>
<td>% Misconception = 53.84</td>
<td>% Misconception = 21.21</td>
</tr>
<tr>
<td>Q9 c)</td>
<td>% Correct = 66.08</td>
<td>% Correct = 71.79</td>
<td>% Correct = 84.85</td>
</tr>
<tr>
<td></td>
<td>% Misconception = 33.92</td>
<td>% Misconception = 28.21</td>
<td>% Misconception = 15.15</td>
</tr>
<tr>
<td>Q9 d)</td>
<td>% Correct = 35.92</td>
<td>% Correct = 65.93</td>
<td>% Correct = 72.73</td>
</tr>
<tr>
<td></td>
<td>% Misconception = 64.08</td>
<td>% Misconception = 34.07</td>
<td>% Misconception = 27.27</td>
</tr>
<tr>
<td>Q13</td>
<td>% Correct = 26.98</td>
<td>% Correct = 73.68</td>
<td>% Correct = 94.29</td>
</tr>
<tr>
<td></td>
<td>% Misconception = 44.54</td>
<td>% Misconception = 0</td>
<td>% Misconception = 0</td>
</tr>
<tr>
<td>Q17</td>
<td>% Correct = 65.78</td>
<td>% Correct = 78.26</td>
<td>% Correct = 94.29</td>
</tr>
<tr>
<td></td>
<td>% Misconception = 4.97</td>
<td>% Misconception = 5.43</td>
<td>% Misconception = 2.86</td>
</tr>
<tr>
<td></td>
<td>% Distractors = 19.17</td>
<td>% Distractors = 16.30</td>
<td>% Distractors = 2.86</td>
</tr>
<tr>
<td></td>
<td>% Didn’t know = 10.06</td>
<td>% Didn’t know = 0</td>
<td>% Didn’t know = 0</td>
</tr>
</tbody>
</table>

In question 13, participants were asked to label the diagram of the heart, indicate on the diagram and explain the flow of blood into and out of the heart. The misconception being tested was “one side of the heart brought blood to the right side of the body and the other
side of the heart brought blood to the left side of the body” cited by (Sungur et al 2001). Both the pre-service teachers and the qualified Biology teachers performed very well in this question giving detailed and accurate answers with neither groups holding any misconceptions, signifying a progression in standard from second to third level education.

However, 44.54% of the senior cycle students examined held the misconception. From the results obtained it is evident that the teachers are very knowledgeable of the topic however may not be delivering the material effectively to the students that they are teaching.

5.16: Performance of Participants in relation to Genetics and DNA

The concepts tested in relation to Genetics and DNA was related to heredity, recessive and dominant traits, organisms that possess DNA and general genetic terminology. Questions 10, 14, 19 and 20 examined these concepts (Appendix 15). Fifteen misconceptions were examined within this section, students and pre-service teachers held all misconceptions while qualified teachers only held 5 misconceptions out of the fifteen examined. In addition pre-service teachers held a higher percentage of misconceptions than the other two groups for five of the misconceptions examined (Table 5.16).

<table>
<thead>
<tr>
<th>Question</th>
<th>Leaving Certificate students</th>
<th>Pre-service teachers</th>
<th>Qualified teachers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q10 a)</td>
<td>% Misconception = 4.18</td>
<td>% Misconception = 0</td>
<td>% Misconception = 0</td>
</tr>
<tr>
<td></td>
<td>% Correct = 95.82</td>
<td>% Correct = 100</td>
<td>% Correct = 100</td>
</tr>
<tr>
<td>Q10 a)</td>
<td>% Misconception = 29</td>
<td>% Misconception = 14.71</td>
<td>% Misconception = 0</td>
</tr>
<tr>
<td>part 2</td>
<td>% Correct = 66.43</td>
<td>% Correct = 93.10</td>
<td>% Correct = 100</td>
</tr>
<tr>
<td></td>
<td>% other = 4.58</td>
<td>% other = 2.94</td>
<td>% other = 44.83</td>
</tr>
<tr>
<td>Q10 b)</td>
<td>% Misconception = 63.30</td>
<td>% Misconception = 3.70</td>
<td>% Misconception = 8.57</td>
</tr>
<tr>
<td>Q14 a)</td>
<td>% Correct = 36.70</td>
<td>% Correct = 96.30</td>
<td>% Correct = 91.43</td>
</tr>
<tr>
<td></td>
<td>% Misconception = 14.71</td>
<td>% Misconception = 9.78</td>
<td>% Misconception = 0</td>
</tr>
<tr>
<td></td>
<td>% Correct = 85.29</td>
<td>% Correct = 90.22</td>
<td>% Correct = 100</td>
</tr>
<tr>
<td>Q14 b)</td>
<td>% Misconceptions = 36.94</td>
<td>% Misconceptions = 5.43</td>
<td>% Misconceptions = 0</td>
</tr>
<tr>
<td>--------</td>
<td>-------------------------</td>
<td>-------------------------</td>
<td>---------------------</td>
</tr>
<tr>
<td></td>
<td>% Correct = 63.06</td>
<td>% Correct = 94.56</td>
<td>% Correct = 100</td>
</tr>
<tr>
<td></td>
<td>% Misconceptions = 30.92</td>
<td>% Misconceptions = 6.52</td>
<td>% Misconceptions = 2.86</td>
</tr>
<tr>
<td></td>
<td>% Correct = 69.08</td>
<td>% Correct = 93.48</td>
<td>% Correct = 97.14</td>
</tr>
<tr>
<td>Q14 c)</td>
<td>% Misconceptions = 0.11</td>
<td>% Misconceptions = 2.17</td>
<td>% Misconceptions = 0</td>
</tr>
<tr>
<td></td>
<td>% Correct = 99.89</td>
<td>% Correct = 97.83</td>
<td>% Correct = 100</td>
</tr>
<tr>
<td>Q19 a)</td>
<td>% Misconceptions = 5.96</td>
<td>% Misconceptions = 6.52</td>
<td>% Misconceptions = 0</td>
</tr>
<tr>
<td></td>
<td>% Correct = 94.04</td>
<td>% Correct = 93.48</td>
<td>% Correct = 100</td>
</tr>
<tr>
<td>Q19 b)</td>
<td>% Misconceptions = 32.15</td>
<td>% Misconceptions = 27.17</td>
<td>% Misconceptions = 0</td>
</tr>
<tr>
<td></td>
<td>% Correct = 67.85</td>
<td>% Correct = 72.83</td>
<td>% Correct = 100</td>
</tr>
<tr>
<td>Q19 c)</td>
<td>% Misconceptions = 0.84</td>
<td>% Misconceptions = 1.09</td>
<td>% Misconceptions = 0</td>
</tr>
<tr>
<td></td>
<td>% Correct = 99.16</td>
<td>% Correct = 98.91</td>
<td>% Correct = 100</td>
</tr>
<tr>
<td>Q19 d)</td>
<td>% Misconceptions = 56.96</td>
<td>% Misconceptions = 21.74</td>
<td>% Misconceptions = 0</td>
</tr>
<tr>
<td></td>
<td>% Correct = 43.04</td>
<td>% Correct = 78.26</td>
<td>% Correct = 100</td>
</tr>
<tr>
<td>Q19 e)</td>
<td>% Misconceptions = 0.84</td>
<td>% Misconceptions = 1.09</td>
<td>% Misconceptions = 0</td>
</tr>
<tr>
<td></td>
<td>% Correct = 99.16</td>
<td>% Correct = 98.91</td>
<td>% Correct = 100</td>
</tr>
<tr>
<td>Q20 a)</td>
<td>% Misconceptions = 20.76</td>
<td>% Misconceptions = 23.91</td>
<td>% Misconceptions = 8.57</td>
</tr>
<tr>
<td></td>
<td>% Correct = 79.24</td>
<td>% Correct = 76.09</td>
<td>% Correct = 91.43</td>
</tr>
<tr>
<td>Q20 b)</td>
<td>% Misconceptions = 58.58</td>
<td>% Misconceptions = 55.43</td>
<td>% Misconceptions = 17.65</td>
</tr>
<tr>
<td></td>
<td>% Correct = 41.42</td>
<td>% Correct = 44.56</td>
<td>% Correct = 82.35</td>
</tr>
<tr>
<td>Q20 c)</td>
<td>% Misconceptions = 25.03</td>
<td>% Misconceptions = 9.78</td>
<td>% Misconceptions = 0</td>
</tr>
<tr>
<td></td>
<td>% Correct = 74.97</td>
<td>% Correct = 90.22</td>
<td>% Correct = 100</td>
</tr>
<tr>
<td>Q20 d)</td>
<td>% Misconceptions = 26.68</td>
<td>% Misconceptions = 29.35</td>
<td>% Misconceptions = 28.57</td>
</tr>
<tr>
<td></td>
<td>% Correct = 74.97</td>
<td>% Correct = 70.65</td>
<td>% Correct = 71.43</td>
</tr>
</tbody>
</table>

The topic of Genetics was identified as being a difficult topic for both students to understand and teachers to teach (Bahar et al. 1999; Cimer 2011; State Examinations Commission 2003; Tekkaya 2001; University of Cambridge International Examinations 2010). The three levels of thought triangle (Johnstone 1991) explains how Biological concepts move from one level to the other in the mind of the learner. In Genetics
observing the morphological characteristics of an animal is the macro level as it is accessible to the learner via their senses. The use of the words alleles and genes to explain the macro brings the learners to the sub-micro level as the concept isn’t directly accessible to their senses. Finally, alleles are then represented and manipulated using mathematical content which is symbolic of the sub-micro level hence it is called the symbolic level (Bahar et al 1999). It can be difficult for the teacher to move intellectually between the three corners of the triangle as well as operating within the triangle when it is required to use all three levels of thought in different proportions (Bahar et al 1999). It can take a long time before teachers and students can move between the three levels and work within the triangle. Students have great difficulty in working in all three levels at the same time (Mbajiorgu and Reid 2006). Participants displayed a high percentage of misconceptions in relation to Genetics in this study. In particular, question 20 parts b) and d). Both misconceptions were cited by Tekkaya (2002). The misconception “Alleles contain genes” was present among all three groups; 58.58% of Leaving Certificate students, 55.43% of pre-service teachers and 17.65% of qualified teachers held this misconception. Similarly, the misconception “Genes are the same as alleles” was prevalent among all three groups; 26.68% of Leaving Certificate students, 29.35% of pre-service teachers and 28.57% of qualified teachers held this misconception. These percentages are notably similar and therefore strongly suggest that third level teacher education does not uncover or resolve this misconception.

5.17: Performance of Participants in relation to The Cell cycle

The concepts examined for the presence of misconceptions were in relation to the different stages involved in the cycle of the cell. Pre-service teachers held a higher percentage of misconceptions than the other two groups for part a (78.16%) and b (40.70%) of question 12. Musa (2010) also found that pre-service teachers held a number of misconceptions in
relation to the cycle of the cell. The 5E learning cycle (engage, explore, explain, elaborate and evaluate) was found to help second level students identify and repair their misconceptions in relation to the cell through a sequence of learning whereby they become engaged in the topic, explore the topic, are provided with explanations from their teacher for their experiences, are provided with opportunities to elaborate and evaluate their learning (Wilder and Shuttleworth 2005).

Table 5.17 Performance of participants in relation to Question 12

<table>
<thead>
<tr>
<th>Question</th>
<th>Leaving Certificate students</th>
<th>Pre-service teachers</th>
<th>Qualified teachers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q12 a)</td>
<td>% Misconception = 65.47</td>
<td>% Misconception = 78.16</td>
<td>% Misconception = 21.21</td>
</tr>
<tr>
<td></td>
<td>% Correct = 34.53</td>
<td>% Correct = 21.84</td>
<td>% Correct = 78.79</td>
</tr>
<tr>
<td>Q12 b)</td>
<td>% Misconception = 30.56</td>
<td>% Misconception = 40.70</td>
<td>% Misconception = 15.63</td>
</tr>
<tr>
<td></td>
<td>% Correct = 69.44</td>
<td>% Correct = 59.30</td>
<td>% Correct = 84.38</td>
</tr>
<tr>
<td>Q12 c)</td>
<td>% Misconception = 66.26</td>
<td>% Misconception = 46.51</td>
<td>% Misconception = 28.13</td>
</tr>
<tr>
<td></td>
<td>% Correct = 33.74</td>
<td>% Correct = 53.49</td>
<td>% Correct = 71.88</td>
</tr>
<tr>
<td>Q12 d)</td>
<td>% Misconception = 45.03</td>
<td>% Misconception = 37.36</td>
<td>% Misconception = 5.88</td>
</tr>
<tr>
<td></td>
<td>% Correct = 54.97</td>
<td>% Correct = 62.64</td>
<td>% Correct = 94.12</td>
</tr>
</tbody>
</table>

5.18: Performance of Participants in relation to Germination and Plant and Animal Reproduction

The concepts examined for the presence of misconceptions were in relation to the germination of a seed, sexual and asexual reproduction in plants and animals. Questions 16 and 18 (Appendix 15) were used to test for these misconceptions. Misconceptions in relation to Germination were found to be prevalent among second level students (Lin 2004). The main trend observed from the data analysed in this study was the students and pre-service teachers held misconceptions in the five misconceptions examined however, the qualified teachers only held the misconception relating to Q18 a). 17.65% (Table 5.18) of the qualified teachers believed that mating was always required for sexual reproduction which is a common misconception held by students and educators (Driver et al 1994). The results indicate that misconceptions in relation to Germination have been identified and
overcome through education but misconceptions relating to reproduction still remain deeply rooted for many.

Table 5.18 Performance of participants in relation to Questions 16 and 18

<table>
<thead>
<tr>
<th>Question</th>
<th>Leaving Certificate students</th>
<th>Pre-service teachers</th>
<th>Qualified teachers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q16 a)</td>
<td>% Misconception = 6.55</td>
<td>% Misconception = 4.71</td>
<td>% Misconception = 0</td>
</tr>
<tr>
<td></td>
<td>% Correct = 93.44</td>
<td>% Correct = 95.29</td>
<td>% Correct = 100</td>
</tr>
<tr>
<td>Q16 b)</td>
<td>% Misconception = 26.24</td>
<td>% Misconception = 6.45</td>
<td>% Misconception = 0</td>
</tr>
<tr>
<td></td>
<td>% Correct = 73.76</td>
<td>% Correct = 93.55</td>
<td>% Correct = 100</td>
</tr>
<tr>
<td>Q18 a)</td>
<td>% Misconception = 42.31</td>
<td>% Misconception = 33.70</td>
<td>% Misconception = 17.65</td>
</tr>
<tr>
<td></td>
<td>% Correct = 57.69</td>
<td>% Correct = 66.30</td>
<td>% Correct = 82.35</td>
</tr>
<tr>
<td>Q18 b)</td>
<td>% Misconception = 26.43</td>
<td>% Misconception = 13.04</td>
<td>% Misconception = 0</td>
</tr>
<tr>
<td></td>
<td>% Correct = 73.57</td>
<td>% Correct = 86.96</td>
<td>% Correct = 100</td>
</tr>
<tr>
<td>Q18 c)</td>
<td>% Misconception = 19.90</td>
<td>% Misconception = 1.09</td>
<td>% Misconception = 0</td>
</tr>
<tr>
<td></td>
<td>% Correct = 80.11</td>
<td>% Correct = 98.91</td>
<td>% Correct = 100</td>
</tr>
</tbody>
</table>

5.19: Summary of Main Findings

Overall the performance of senior cycle students, pre-service and qualified teachers in the misconceptions in Biology identification instrument affirmed the existence of misconceptions among these three groups in Ireland. From analysing the results the following points were deemed particularly significant:

- There was a statistical significant difference (P<0.001) between the three groups when the mean percentage of misconceptions held and correct responses obtained was compared. The qualified teachers held fewer misconceptions and answered more questions correctly than the pre-service teachers and senior cycle students.

- There was no statistical significant difference found between gender and age in relation to performance in the identification test.

- The level at which participants studied Junior Cycle Science and Senior Cycle Biology was seen to have a statistical significant difference on their performance.
Participants studying at higher level performed much better. Similarly, third year pre-service teachers performed better than second year pre-service teachers.

- The type of school students attended had no statistically significant difference on the mean percentage of misconceptions held but did have a statistical difference on the mean percentage of correct responses obtained in the identification test.

- The grades the participants achieved in their state examinations were statistically significant in relation to their performance at Junior Certificate but there was no statistical significant difference found at Leaving Certificate level.

- No statistically significant relationship was noted between years of service and performance in the identification test.

- In relation to the specific Biology topics analysed, all three groups held misconceptions in Photosynthesis, Respiration and Ecology. The pre-service and qualified teachers held no misconceptions in relation to The Circulatory System topic; where they were asked to label the different chambers, arteries, veins and valves of the heart and to explain the blood flow to and from the heart while 44.54% of students held misconceptions. Both the students and pre-service teachers held high percentages of misconceptions in relation to the Genetics and DNA concepts examined while the qualified teachers only held five out of the fifteen misconceptions examined.
6.1: Introduction

The results of the data analysis from phase two of this investigation are presented in this chapter. The focus of the chapter was to analyse and discuss the results obtained from evaluating the voluntary additional pedagogy module completed by third year pre-service teachers in the University of Limerick and the website as a useful tool to promote conceptual change among teachers and students. Phase 1 of the study has already identified that misconceptions are prevalent among senior cycle students, pre-service teachers and qualified teachers. The research questions 2, 3 and 4 (Chapter 4) identify the need for incorporating conceptual change effectively into the science classrooms; this intervention doesn’t some without challenges.

6.2: Evaluation of Additional Pedagogy Module

6.2.1: Question 1: What was your Overall Impression of the Module?

Question one of the evaluation form was to identify the pre-service teachers overall impression of the module that was delivered. The question was answered using a likert scale ranging from excellent to unsatisfactory and all participants (n=51) responded. Figure 6.1 represents the frequency of responses and indicates the valid percentages of the cohort.
Figure 6.1 Responses pre-service teachers to question 1 of the Evaluation form

The results from question one are for the most part very positive as 49.02% of the cohort rated the module as excellent, 31.37% felt it was very good, 15.69% found it to be good and 3.92% found the module satisfactory. None of the respondents found the module unsatisfactory. It is important to note here the differential power of the relation with the tutor (author) and the third year pre-service teachers. As the pre-service teachers were familiar with the tutor they were less likely to rate the additional pedagogy module poorly even if they felt so as they would have built a good student-tutor relationship and appreciated the hard work that had gone into its implementation (Apple 2014). If this evaluation was distributed to the pre-service teachers and if they knew it was being analysed by someone else the findings may differ to what is presented above.
6.2.2: Question 2: What do you think were the Main Strengths of this Module?

This question was an open ended question, the data was organised into 6 categories (Figure 5.2). The percentages of the varying responses are represented on Figure 5.2.

![Image of bar chart showing percentages of responses to the question on main strengths of the module.]

Figure 6.2 Responses of pre-service teachers to question 2 of the Evaluation form

The six categories were; design and structure of lesson plans, relevant to subject area, effective teaching strategies, improvement in ICT skills, identification of misconceptions and practical and creative resources. 29.41% of pre-service teachers identified ‘effective teaching strategies’ as the main strength of the module. This is important as prior to this additional pedagogy module the pre-service teachers had very little exposure to the use of teaching strategies to help identify and overcome misconceptions. These strategies include; analogies (Clement and Brown 2004), concept mapping (Broggy and McClelland 2008), conceptual change text (Naylor and Keogh 1999), Science reflective journals (Towndrow 2008), concept cartoons (Akamca et al 2009) and digital storytelling.
(Mcelellan 2007). When delivering the module the pre-service teachers’ awareness of misconceptions and conceptual change strategies was limited. Science learning is heavily loaded with misconceptions (Vosniadou et al 2001); yet despite this, the pre-service teachers who participated in the module had a very low level of understanding of how to identify misconceptions using teaching strategies in their planning. Furthermore it was highlighted that prior to the module pre-service teachers hadn’t been introduced to literature outlining misconceptions or conceptual change strategies to overcome misconceptions. Such findings indicate a serious concern about the thought process and methodologies that pre-service teachers will use in the classroom. Misconceptions are resistant to change and will not be overcome by traditional teaching strategies, this has been well documented (e.g. Cakir 2008; Kendeou and van den Broek 2008). Teachers need to be provided with examples of successful implementation strategies as well as opportunities to put them into practice (Keys and Bryan 2001). Without educating pre-service teachers to overcome their own misconceptions, as well as identify their students’ misconceptions they are being introduced into an unremitting cycle where misconceptions remain dominant.

21.57% of respondents identified ‘resources’ as a main strength of the module, it was highlighted that these were both practical and creative. The author was mindful that the resources were practical, easily attainable and did not incur large costs as the pre-service teachers are self-funded on teaching practice. 13.73% of the respondents found that the design and structure of the lesson plans were very effective. An equal number of respondents found that the identification of misconceptions was a strength of the module with comments such as “I didn’t realise I had so many misconceptions”, “I am glad I have identified some of my own misconceptions before TP”, “I have learned that I have transferred some of my own misconceptions on to students during my second year
teaching practice”. 11.76% felt the material was very relevant to their subject area; a student added “We have done lots of education modules but none relevant to Science, all very general”. Only 9.80% felt that their Information Communication Technology (ICT) skills had improved. This is something that needs to be looked at and developed further as many researchers have stated that the use of ICT stimulations and video clips can bring material to life for students and help advance their conceptual understanding especially visual learners (Ruddick and Parrill 2012; Van Garderen 2006).

The comments recorded above indicate that they acknowledge that they possess a variety of misconceptions in Biology which they would have brought with them into the classroom if they hadn’t been made aware of them and given an opportunity to explore their understanding of the concepts. This is a significant problem as it is safe assume that pre-service teachers in other year groups in the University of Limerick (Galvin and O’Grady 2012) and pre-service teachers in other teacher training colleges do possess misconceptions similar to the pre-service teachers involved in this study. Teachers holding their own scientific misconceptions are unlikely to be able to identify their students’ misconceptions or provide educational experiences to overcome students’ incomplete ideas to overcome misconceptions (Burgoon et al 2011).

6.2.3: Question 3: If you could improve one aspect of the ways in which this Module is taught, what would it be?

Question 3 looked at possible improvements that could be made to the module going forward. This was an open ended question and the responses were categorised as per Figure 6.3.
43.14% of the respondents referred to the weekly timeslot of the module rather than the actual content of the module. This emphasises how pre-service teachers decisions to attend such module is impacted by their timetable similar to teachers are restricted to attending different CPD opportunities due to time constraints and timetabling. They also thought that six weeks was very short, and it was suggested that the module should have been run for the entire semester. As the lecturers in the University didn’t want the pre-service grades in their modules to be affected by the extra work involved in this module they insisted that the module wasn’t longer than six weeks, further emphasising the constraints of society. Other improvements suggested were to increase the amount of group work (13.73%) and more practical exercises (43.14%). The logistics of the module hindered both of these as the facilitator did not have access to a laboratory and the room was to full to cater for a group work setting. Ideally this module should be facilitated in a laboratory setting. Similar to the constraints identified in the proposed senior cycle Biology reform, schools require access to good working laboratory, laboratory technician and relevant
resources for students to fully achieve the outcomes set out in the proposed syllabus. However, these facilities may not always be accessible (Hyland 2014).

6.2.4: Question 4: Relative to other University Modules you have taken, the amount of effort you put into this Module was higher/average/lower.

This question was a multiple choice question, where pre-service teachers were required to choose from three responses and were asked to explain why. All participants chose a response from the three given answers however very few gave a reason for their choice of response. See Figure 6.4 for the frequency of participants’ answers.

![Figure 6.4 Responses of pre-service teachers to question 4 of the Evaluation form](image)

<table>
<thead>
<tr>
<th></th>
<th>Higher</th>
<th>Average</th>
<th>Lower</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>10</td>
<td>28</td>
<td>13</td>
<td>51</td>
</tr>
</tbody>
</table>

Figure 6.4 Responses of pre-service teachers to question 4 of the Evaluation form

It is evident from Figure 6.4 above that more than half (54.90%) of the cohort said they gave the module average effort, reasons for this were “We have so much on our timetable already”, “I have no time”, “It’s too late in the evening I’m really tired”. Similar responses were recorded for the percentage of pre-service teachers that chose lower (25.49%) with an additional comment from three pre-service teachers “because the assessment is worth less than my other modules”. 19.61% of the respondents felt they put more effort into this
module than other university modules because “it’s relevant”, “it’s/she’s interesting”, “She wants us to do well and has a great passion for the subject”, “I feel it is the most beneficial module so far for teaching practice”. It is evident from the responses above that for some the attitude of the tutor influenced the effort they made. It is well documented that a teacher that is passionate about their subject can a positive influence on students’ attitudes and achievements (Hattie 2003). However, on the other hand (25.49%) of the pre-service teachers admitted to spending less time as the other modules were worth more to them, this was just voluntary. This emphasises again people’s perceptions, that if they didn’t have to do it in the first place they didn’t need to put a whole lot of effort into it, would findings like this suggest that in situations where teachers aren’t required to fully engage in CPD they wouldn’t either? Would providing a professional grading for CPD encourage more teachers to fully engage with what education and training is out there? (Lynch et al 2013).

6.2.5: Question 5: After completing this Module have your feelings towards Reflective Practice become more positive?

Third year pre-service teachers were introduced to reflective writing in their second year teaching practice. It was highlighted by lecturers and tutors alike that pre-service teachers found this procedure very monotonous with a tendency to focus mostly on classroom management and timing, allowing little reflection on the subject matter. One of the aims of this module was to promote reflective practice and to identify the benefits of it in the classroom both for the teacher and their students. This was done mainly through discussions with the class as a whole group and introducing the Science reflective journal writing. Question five required the pre-service teachers to choose whether they thought their opinions towards reflective practice had changed by choosing yes or no as a response.
90.20% of respondents said that on completing the module their feelings towards reflective practice have become more positive. Some of the comments that pre-service teachers added were “I used to just get reflections from my friends and change them around”, “I never really knew the benefit of them”, “I will definitely use the Science reflective journals when on teaching practice they’re a great idea to check students understanding and to get students to reflect on their own work”, “I now know how to reflect on the Science and not just on planning and organisation”, “I never thought about how the way I’m teaching something or the resource I’m using could have such an impact on the students’ understanding/misunderstanding”. 9.80% felt that their attitudes towards reflection hadn’t changed, “if I copy and paste a few things from last year I’ll still do grand”, “It’s easier to reflect on time management, planning and organisation it requires less thinking”, “Well I got an A in second year”. According to Erduran (2003), a lack of effective communication between students and teachers can lead to a mismatch between what is taught and what is learned. In the context of Science lessons, symmetry between the nature of teachers’ understanding of a particular Science topic and students’ ideas regarding the topic is critical, because such a match illustrates what scientific knowledge is being taught and learned in the classroom. If neither teacher nor student reflects on the teaching and learning that has taken place this will not be achieved. Reflective practice and providing students with feedback of their work is an important key for developing a ‘thinking’ teacher and ‘thinking’ student. Reflective practice supports the higher order complexity model of CPD that is needed for this intervention (Hattie and Timperley 2007). Promoting reflection in the classroom can help the teacher to distinguish the concepts that are understood by the students and the concepts that still need more work and exploration (Hatton and Smith 1995; Loughran 2002). It is evident that there are still a few that are not seeing the benefits of reflection. It is very difficult to convince every pre-
service teacher of the benefits of the practice when they see there is an easier route as they are overloaded with material to get through in other modules. It is also evident for some that they will gauge what they do on the grades they receive the participant that got an “A” last year on teaching practice wasn’t going to change the way he/she reflects because it came down to the grade for him/her, emphasising accountability and measurability of our society as well as the reluctance of teachers to change (Hargreaves 2005).

6.2.6: Question 6: Do you think the topic Misconceptions should be included in the Third Year Pedagogy Module for the future?

Pre-service teachers were asked to choose either yes or no on the inclusion of identification of misconceptions in their pedagogy teacher education and were asked to provide an explanation for their answer. Similar to other questions discussed on the evaluation form, all of the cohort responded either yes or no but very few provided an explanation for their response. See Figure 5.6 for the frequency of yes or no responses.

It is important to be aware of the differential power associated with this type of question; pre-service teachers may not want to offend the tutor (Apple 2014). 94.12% of the respondents answered yes, of these responses included; “Because I have a lot of them”, “I have a lot of misconceptions and I think pre-service teachers in my own subject area and in other subject areas have them too”, “Because if we don’t we will instil them in the students we teach, there will be no end to the cycle”, because it’s interesting to test our understanding and not just our memorisation”. It is well documented that pre-service teachers are often unaware of their students’ misconceptions (Halim and Meerah 2002) because they hold the misconceptions themselves. 5.88% of the pre-service teachers felt there wasn’t any need to include the topic of misconceptions into the pedagogy modules, one respondent added “we have too much to learn as it is”. Many teachers in society are of
the same view as these pre-service teachers, ‘why learn anymore? We have our qualification!’ (Cordingley et al 2005; Darling-Hammond and Mclaughlin 1995).

The teacher is responsible for guiding students through the learning process based on student’s abilities and prior knowledge and using the most effective methods of teaching (Loizou and Papademetri-Kachrimani 2011). It is also necessary for them to learn how their students learn in order to help their students understand the concepts they are teaching (Ausubel et al 1968). Without this pedagogy module pre-service teachers are not achieving these outcomes in their initial teacher education programs at present. It is imperative that pre-service teachers learn to recognise and reduce misconceptions as students’ misconceptions are less possible to be changed after a lesson which didn’t acknowledge them (Louisa et al 1989). Knowledge of how to analyse subject-matter content is necessary for good instructional planning and instruction (Abimbola and Baba 1996; Özmen 2004). Science teachers who possess this skill would be able to act as filters for misconceptions and alternative conceptions, thereby preventing them from getting to their students as “knowledge” and interfering with their learning (Abimbola and Baba 1996). Teachers at the primary and secondary education levels and the Lecturers at the university assume very important roles regarding the identification of their own misconceptions and the employment of alternative teaching strategies to eliminate or at least minimise the misconceptions of their students.

6.2.7: Question 7: What have you learned about Misconceptions after completion of the Module?

This question was an open ended question; the following six categories were assigned to the data once examined thoroughly see Figure 6.5.
Of the six categories, the predominant response (29.41%) was “how they’re formed, identified and overcome”. This addressed one of the main aims of the module, where it was acknowledged that pre-service teachers had rarely been formally introduced to misconceptions or how teachers can help identify and overcome them in their classroom. 15.69% of the pre-service teachers learned how important it is to know your subject while another 15.69% learned that the resources and representations that they use can contribute to the formation of misconceptions. Content knowledge is essential in overcoming misconceptions as poor content knowledge contributes to the formation of misconceptions (Smith 1999). It is important for teachers to constantly develop their own Science knowledge and try to tackle their own misconceptions (Johnston 2005). There is certainly an assumption that secondary school teachers have adequate subject matter knowledge and
are competent in translating their knowledge into curriculum materials for instruction in the classroom, but for many this is not the case (Mak et al 1999). By getting acquainted with the specific conceptions and ways that students reason, pre-service Science teachers can start to restructure their subject matter knowledge into a form that enables productive communication with their students (Lederman et al 1994). With reference to using resources and representations that may contribute to the formation of misconceptions it comes down to knowing and understanding the subject matter and to be able to identify where the resources and representations that are in a textbook or on a worksheet fall short. As pedagogical content knowledge refers to the ability to transform subject matter knowledge in a manner accessible to learners, the development of Pedagogical Content Knowledge (PCK) depends to large extent on the teachers’ subject matter knowledge (Smith 1999). It is the teachers’ role to ensure that the resources and representations they use are explained properly so misconceptions are less likely to arise (Güler and Yağbsan 2008). Teachers should be educated to use textbooks more critically and selectively, and be alert to the inaccurate information described in textbooks (Yip 1998a).

13.73% of the cohort identified the importance of checking students’ understanding and not just the grade. Pre-service teachers wrote “I always gave the student the percentage they got in the test but never checked if they understood it”, “I would have gone through the test with the students that got C and D grades but the students that got an A or a B I presumed they understood the material”. It was well documented in phase one of this research investigation that the grade a student receives in state examinations doesn’t always reflect on their understanding of the concepts it merely suggests they have a good memory. Students can produce right answers to problems without really understanding much of the Science involved (Lythcott 1990). Subjects such as Senior Cycle Biology are heavily theory based as a result students tend to learn and memorise facts and obtain their
knowledge according to slogans and rigid frameworks. They tend to know facts, rules and formulas but have very little understanding of the actual meaning or the context of the phenomena (Nahum et al 2004).

9.80% of the pre-service teachers learned how easily misconceptions can be picked up and how deeply rooted they can become. An equal number of the pre-service teachers felt they had passed their own misconceptions on to students they had taught during their second year teaching practice; highlighting the importance of the teacher in overcoming misconceptions among the students they teach (Gomez-Zwiep 2008). Finally, 5.88% of the pre-service teachers realised that oversimplifying material can contribute to misconceptions. This is mindful of the fact that some Biological concepts are very abstract and need to be simplified to a certain extent when dealing with different age groups as the material would be too difficult for them to comprehend, while not allowing for oversimplification

6.2.8: Question 8: I will use the Teaching Strategies/Resources presented in this Module on my Fourth Year Teaching Practice.

Question 8 was answered using a likert scale ranging from strongly agree to strongly disagree. The frequency of responses from the question is represented in Figure 6.8.
Figure 6.6 Responses of third year pre-service teachers to question 8 of the Evaluation form

Figure 6.6 shows that all the pre-service teachers (n=51) that completed the evaluation form either agreed or strongly agreed with the statement that they would use the teaching strategies and resources while on their fourth year teaching practice. Almost three quarters of the cohort (72.55%) strongly agreed with the statement while 27.45% agreed with the statement. This was a very promising result to obtain as all pre-service teachers indicated that they would implement what they had learned from the module. The teaching strategies in this module acknowledge the presence of students’ misconceptions, which will help them to plan lessons and reshape the students’ misconceptions into correct concepts. Such lesson plans will enable the students to experience phenomena which contradict their current misconceptions for the purpose of inducing conceptual change (Valanides 2000). If higher education institutes could implement a module similar to this intervention programme into their initial teacher education courses they could help break
the cycle of misconceptions. Teachers would be able to identify their own misconceptions and be provided with the skills, knowledge and support to help identify, reduce and ultimately overcome the misconceptions of their students.

6.3: Evaluation of the Website Resource

As stated in previous chapters, it was much easier to access the third year pre-service teachers as the author was based in the University. It was more difficult to gain access to qualified teachers already in the workplace, therefore the website resource was set up so the qualified teachers had access to the information and resources on how to identify and tackle misconceptions. It was safe to assume from the results obtained in phase 1 of this research that qualified Science teachers did hold misconceptions and may be propagating them to their students. In order to assess the success of the website resource, an evaluation form was distributed to all of the current members of the website (n=154). The evaluation form consisted of six questions, with a likert scale for answering.

![Figure 6.7 Q1: A representation of how useful the members found the website resource](image)
65% agreed and 19% strongly agreed that the website was a useful resource for their teaching. This was a promising result however, 12% were unsure and 4% disagreed therefore, one can conclude that there is certainly more work needed to improve the usefulness and relevance of the resource. As the author was only able to visit the qualified teachers that were in the teaching practice schools to explain the website it may be of benefit to visit more schools to explain the contents to the teachers or create a video link on the website explaining the different resources available to them on the site and where they can access them as people find it easier to understand if it is visually explained to them (Berk 2009).

The second question was how often the members accessed the resource. They had four options to choose from; twice a week, once a week, every two weeks and once a month.

![Figure 6.8 Q2: A representation of how often the members accessed the website](image)

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Twice a week</td>
<td>10%</td>
</tr>
<tr>
<td>Once a week</td>
<td>30%</td>
</tr>
<tr>
<td>Every two weeks</td>
<td>20%</td>
</tr>
<tr>
<td>Once a month</td>
<td>20%</td>
</tr>
</tbody>
</table>

**Figure 6.8 Q2: A representation of how often the members accessed the website**
The most common response was once a week (36%), only 10% accessed the website twice a week, 28% accessed it every two weeks and 26% used the resource once a month. These results may be reflective of how ‘exam driven’ the teachers are and hence 54% accessed the website every two weeks or less. Teachers are focusing on exam papers and marking schemes rather than identifying misconceptions and challenging their own and their students understanding of concepts as they are pressured by students, parents and principals to cover the syllabus and achieve high grades in the Leaving Certificate (Hennessy et al 2011). In addition the members who were pre-service teachers were studying for their Christmas exams at the time and so, were very busy and may not have required the resources on the website at this particular time of year.

The third question required them to identify the most useful section of the website. There were five sections; literature, misconceptions, teaching strategies, lesson plans and the Biology syllabus.

Figure 6.9 Q3: A representation of the sections of the website that the members found most useful
Teaching strategies was found to be the most beneficial section of the website with 30% of
the members selecting it. The teaching strategies section provided information and
examples on concept maps, concept cartoons, Science reflective journals, model building,
alogies, conceptual change text and digital media resources. It is the most developed
section of the website at present along with the literature section which was chosen by
21% of those questioned. 18% felt that the list of misconceptions per topic was useful, this
could be organised better into sections within a topic rather than one big topic which may
make it easier to select the relevant misconceptions for the class. Only 16% felt the
Biology syllabus was a useful section, this section comprised of exam papers, class tests
and marking schemes which a lot of qualified teachers may have themselves already as the
Irish School system is so exam orientated (Hennessy et al. 2011; Mooney Simmie 2007),
therefore these materials and resources weren’t new to all of them. Finally, 15% felt the
lesson plans were useful, this lower percentage may contribute to the fact that teachers feel
that it is difficult to deliver someone else’s lesson as everyone has their own style (Flores
and Day 2006) and so providing lesson guidelines similar to the photosynthesis module in
phase 3 may be of greater benefit.

Question 4 asked the members how they felt about the layout and ease of access to the
material on the website.
37% strongly agreed and 58% agreed with this statement that the website had a clear layout and the material was easy to find. This is a promising result as a lot of time went into the designing of the website; selecting relevant sections, resources, choosing imagery and suitable text. For a website to be a successful resource the material must be appealing to the eye and information must be easily accessible (Gehrke and Turban 1999). 5% were unsure with this statement and so, there is room for improvement of the website.

Question 5 asked the members if they would recommend this website resource to other Science colleagues.
57% strongly agreed and 38% agreed that they would recommend the website resource to other Science teachers. As it wasn’t possible to visit all universities and secondary schools to present the website this is encouraging to see the majority of the members (95%) will hopefully recommend the resource to their colleagues and will in turn result in a rise in members and the sharing of useful resources. 4% were unsure and 1% said they wouldn’t recommend the website resource. As teachers stated in their interviews, although teaching for conceptual understanding is desirable it isn’t always achievable due to exam constraints and school pressures therefore, this might account for the 5% that wouldn’t recommend this resource to other Science teachers as regardless of how good the resource may be they still won’t have time to incorporate the suggested teaching strategies while preparing for the terminal exams (Yerrick et al 1997).
Question 6 asked the members if they agreed with the statement that the website was a useful resource for teachers that weren’t aware of misconceptions.

![Bar chart showing responses to Question 6](image)

**Figure 6.12 Q6: A representation of whether the members felt that the website was useful to teachers who were unaware of misconceptions**

49% strongly agreed and 38% agreed with this statement that the website was a good resource for teachers who were unaware of misconceptions. 10% were unsure, 2% disagreed with the statement and 1% strongly disagreed with the statement. This suggests that 87% of the website members felt that the website was an informative resource in relation to misconceptions and felt they learned more about how they are developed, identified and overcome which is one of the main aims set out by this project. However, 13% are still not convinced of its usefulness to teachers who are unaware of misconceptions, they may find there isn’t any need or time for in the science classroom for promoting conceptual change using this resource or possibly that they can only learn from
participating in the development of the intervention themselves (Biesta and Miedema 2002).

6.4: Summary of Main Findings

6.4.1: Importance of Subject Matter Knowledge

From evaluating the module the author predominantly suggests that subject matter knowledge plays a key role in the development and effectiveness of a teacher. Increased Science knowledge leads to greater confidence and better enactment of inquiry and engagement in the classroom (Sullivan-Watts et al 2013). Good Science content knowledge guides the planning of an effective lesson (Luera et al 2005). Teachers lacking good Science content knowledge will tend to avoid questions from students and fail to develop their students’ conceptual understanding of important topics (Abell 2008). In order to tackle deep rooted misconceptions among students, teachers need to be competent in the material themselves and encourage exploration and questioning of the concepts. It is imperative that teachers are constantly developing their subject matter knowledge to ensure elimination of their own misconceptions (Johnston 2005).

6.4.2: Amplification of Exams

One of the major problems associated with the teaching and learning of Biology in Ireland is the tendency of both curriculum setters and teachers to focus on the excessive use of facts and information. It has been well documented that such an excessive use of facts results in the use of rote learning to gain knowledge in relation to Biological concepts. Rote learning of such concepts results in a poor level of higher cognitive understanding of complex Biological concepts. In cases such as this, misconceptions are not challenged or brought to light, allowing learners to hold onto their misconceptions throughout their formal education (Mintzes et al 2001). The strong tendency to focus on recall and didactic teaching methods within the field of Biological education in particular leads to poor depth
of knowledge (Allen and Tanner 2006). For many teachers the impact of the students’ grades greatly influences the teachers’ status and reputation thus many teachers prepare their students solely to answer the questions in the exam and not develop their understanding (Nahum et al 2004). Research supports the idea that teachers although aware of misconceptions don’t have the time to identify them among their students and are often forced to assume a common level of their students’ knowledge as a result of exam pressure (Chen et al 2006). However, time pressure shouldn’t be used as an excuse; but rather as an opportunity to encourage collaboration among teachers, for example teachers in the Science department could collaborate together to record the predominant misconceptions in Science, one teacher could take physics misconceptions, while the other teacher records the Biology misconceptions. This would encourage interaction among colleagues and have the students’ best interest in mind (Collinson and Cook 2001).

6.4.3: The Effect of Teachers’ Understanding of Misconceptions on Students Learning

Research suggests that many teachers are aware that students hold misconceptions but due to syllabus and exam time constraints they are forced to assume a common level of students’ knowledge in order to get the material covered in time (Chen et al 2006). A lesson is much more likely to be successful if teachers choose to elicit and acknowledge students’ possible misconceptions (Allen 2014). As highlighted in phase one of this study students hold similar misconceptions, therefore it is safe to assume that if one student expresses a misconception in class it is very likely that others hold it too; therefore tackling the misconception will positively influence the whole class (Valanides et al 2000). By underestimating the effect of misconceptions students learning is affected since they will not be able to fully achieve their learning objectives as the misconceptions will stand in their way of accepting learning and remembering the correct scientific concept.
Teachers’ lack of awareness of the obstacles that are created as a result of ignoring students’ misconceptions will lead to students’ struggling to develop their conceptual knowledge (Kambouri 2014). The pedagogy module has emphasised the importance of the teachers’ role in providing opportunities for students to permit their misconceptions without the teachers awareness they will go unchanged (Ravanis and Bagakis 1998). Similarly in the initial teacher education it is the role of the lecturer to help the pre-service teachers identify their own misconceptions, a pre-service teacher noted in their evaluation of the module “I didn’t realise I had so many misconceptions”. This further highlights that misconceptions regardless of teacher or student will remain unchanged unless identified.

6.4.4: Teachers’ Education on Misconceptions

It is evident from analysing the results obtained from the evaluation forms that the education that teachers receive with regard students and the identification of their misconceptions is limited (Galvin et al. 2015). As the additional pedagogy module delivered to the third year pre-service teachers in the University of Limerick was the first formal introduction of misconceptions to them, it is safe to assume that many of the practicing Biology teachers observed know little if anything about identifying or tackling misconceptions their students may hold. For many teachers it is through experience that they recognise the importance of students prior knowledge and misconceptions and realise that ignoring them and hoping students will overcome them on their own is unfair and unachievable (Schmidt 1997). From evaluating the module 94.12% of the cohort felt the need to integrate the topic of misconceptions into the pedagogy module, a pre-service teacher added “I have a lot of misconceptions and I think pre-service teachers in my own subject area and in other subject areas have them too”. The pre-service teachers appreciate the need to understand misconceptions and want to develop their knowledge and
awareness of them in order to overcome their own misconceptions and tackle their students effectively.

6.4.5: Traditional Teaching versus Constructivist Approach

The traditional view of knowledge is that it can be transferred directly from the teacher to the learner. This method of teaching assumes that the learner has no prior knowledge or ideas and so, clearly explains why learners are frequently referred to as ‘blank slates’. This term reinforces the belief that learners have no pre-existing knowledge and more importantly, no relevant knowledge of the information they are about to learn. Pre-service teachers expressed that they were used of observing this type of teaching while on their second year teaching practice as well as their experience of second level education where the teacher was the centrepiece for instruction while the students absorbed the information and regurgitated it back when requested to do so. This type of environment provides incentives for learning at surface level only by encouraging students to learn superficial indicators of knowledge rather than an understanding of fundamental principles (McCarthy and Anderson 2000). It stifles creativity and is no longer sufficient for educating a classroom of students (Zhao 2011). It promotes passive learning amongst students when the goal should be to achieve understanding through active, meaningful learning. Using a constructivist approach to teaching ensuring a student centred environment is much more effective in tackling misconceptions than didactic teaching. Constructivism when used with care encourages students to share ideas and construct their own learning be it independently or in small groups (Hoover 1996). These types of lessons which elicit debate and argumentation will enable students to experience phenomena that will contradict their previous beliefs and induce conceptual change by restructuring the concepts (Pine et al 2001; Valanides 2000).
6.4.6: Implications for Teachers, Teacher Education and Policy Makers

The widespread presence of misconceptions among second level students and pre-service teachers discussed in phase one and two of the results; suggests that Biology teachers are unaware or unconcerned with identifying students’ misconceptions and are not using conceptual change strategies. The need for high quality Science graduates in Ireland is imperative (Department of Jobs, Enterprise and Innovation 2011); yet our second level students are evidently achieving high Leaving Certificate grades from rote learning as opposed to true understanding of scientific concepts. It is essential that pre-service teachers are provided with adequate education and tutoring to tackle misconceptions and develop conceptual understanding in their classrooms as well as sustaining good practice among qualified teachers (Sullivan-Watts et al 2013). Policy makers and curriculum setters should also bear in mind that students’ construct their knowledge at different rates and their experiences may vary (Johnston 2005). For teachers to help individual students to identify and overcome their misconceptions it is crucial that time is allocated within the curriculum to provide these opportunities to occur (Russell and Watt 1990). The findings from the investigation should concern researchers, teacher educators, teachers and policy makers since it suggests that teachers are not properly informed and prepared for their complicated and challenging roles (Howitt 2007).
Chapter 7: Results and Analysis of Phase 3

7.1: Introduction

The results of the data analysis from phase 3 of this investigation are presented in this chapter. The focus of the chapter was; to analyse and discuss the results obtained from the pre and post identification instruments distributed to the experiment and control groups, to evaluate the success of the module on pre-service teachers’ teaching and students learning. The data collected from the interviews with the pre-service teachers that implemented the lesson guides are also presented and discussed. This phase of the study investigates the effectiveness of the suggested teaching strategies found in the literature and their ability to identify, reduce and ultimately overcome students’ misconceptions and the impact teacher education and training on conceptual change has on teachers’ teaching of the topic.

7.2: Part 1 of the Identification Instrument - Two-Tier Multiple Choice Questions

Part one of the identification instrument consisted of 13 multiple choice questions. In the pre-tests an independent t-test produced the mean scores for the experiment group (M = 4.46 ± 1.8) and the control group (M = 4.27 ± 1.7) which showed no significant difference (p-value= 0.326), suggesting a similar academic ability among the two groups. In the post-tests, the mean scores of both the experiment and the control group increased, reaching 11.25 ± 1.3 and 6.34 ± 2.0 respectively. A p-value of P<0.001 suggested a highly significant difference in the post-tests between the groups. When the mean increments from the two groups were compared (experiment vs. control, 6.79 ± 2.0 and 2.09 ± 1.6) a p-value of P<0.001 revealed a highly significant difference in the students’ conceptual understanding between the two groups in part one of the identification instrument.
Table 7.1 The mean scores of the pre-tests and post-tests, and the increase in mean scores for the experiment and control group in part 1 of the Identification Instrument

<table>
<thead>
<tr>
<th></th>
<th>Pre-test</th>
<th>p-value</th>
<th>Post-test</th>
<th>p-value</th>
<th>Mean increment</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Experiment</strong></td>
<td>4.46 ± 1.8</td>
<td>0.326</td>
<td>11.25 ± 1.3</td>
<td>&lt;0.001</td>
<td>6.79 ± 2.0</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td><strong>Control</strong></td>
<td>4.27 ± 1.7</td>
<td></td>
<td>6.34 ± 2.0</td>
<td></td>
<td>2.09 ± 1.6</td>
<td></td>
</tr>
</tbody>
</table>

The correct students’ responses for each question were compared between the experiment and control groups. Out of the thirteen questions, the chi-square test indicated that four questions showed significant differences (P< 0.05) between the students’ responses from both groups. The four questions were questions 2, 8, 10 and 11 (refer to Tables 7.2, 7.3, 7.4 and 7.5). The post-test results indicated that the experiment group had a significantly better conceptual understanding towards what gases are taken in by green plants (Question 2), when plants respire (Question 8), the reactants and products involved in Photosynthesis (Question 10) and the important factors required for the process of Photosynthesis in plants (Question 11).

Table 7.2 The number and percentage of students who correctly answered Question 2 in their pre and post-tests for both groups and the mean scores (pre and post-tests) with the mean increments for both groups.

<table>
<thead>
<tr>
<th></th>
<th>No. of students answered correctly</th>
<th>% answered correctly in Pre-test</th>
<th>Pre-test mean score</th>
<th>p-value</th>
<th>No. of students answered correctly</th>
<th>% answered correctly in Post-test</th>
<th>Post-test mean score</th>
<th>p-value</th>
<th>Mean increment</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Experiment</strong></td>
<td>85/173</td>
<td>48.6%</td>
<td>0.49 ± 0.50</td>
<td>0.241</td>
<td>121/173</td>
<td>70.0%</td>
<td>0.70 ± 0.46</td>
<td>&lt;0.001</td>
<td>0.21 ± 0.80</td>
<td>0.003</td>
</tr>
<tr>
<td><strong>Control</strong></td>
<td>75/175</td>
<td>42.9%</td>
<td>0.43 ± 0.50</td>
<td></td>
<td>68/175</td>
<td>38.9%</td>
<td>0.39 ± 0.49</td>
<td></td>
<td>-0.04 ± 0.72</td>
<td></td>
</tr>
</tbody>
</table>

For question 2, the pre-test mean scores for the experiment group and the control groups were 0.49 ± 0.50 and 0.43 ± 0.50 respectively. A p-value of 0.241 indicated no significant difference between the students’ conceptual understandings between the two groups. In the post-test, the mean scores for the experiment and control group were 0.70 ± 0.46 and 0.39 ± 0.49 respectively. The mean scores of the post-tests between the two groups were significantly different (P<0.001). When the pre-tests were compared to the post-tests, the
mean scores for the control group had slightly decreased by 0.04 ± 0.72, and the experiment group had increased by 0.21 ± 0.80. The difference of the mean increment scores between the two groups was significant (P=0.003). The results suggest that students from the experiment group had a better conceptual understanding about what gases are taken in by green plants which was comparable to findings by Yenilmez and Tekkaya’s (2006). 70.0% of the experiment group answered this question in their post-test correctly, choosing oxygen gas as the gas that is taken in, in large amounts by the plant when there is no light energy, compared to 38.9% of the control group. Comparable to the Cibik et al (2008) study, the students in the experiment group explored the materials required for Respiration by firstly having a class discussion, discussions (Balci et al 2006; Ekici et al 2007; Yenilmez and Tekkaya 2006) play a vital role in overcoming misconceptions, as students are unlikely to change their belief if they are just told that their idea is wrong (Ekici et al 2007), secondly investigating Respiration using woodlice and testing for the gases that were released, and thirdly by watching a video clip of the process of Respiration. The students need to test and see results in order to change the concepts in their mind (Kici 2012). Students must become dissatisfied with their existing conditions and new concepts must provide a better explanation and be understandable in order for them to address their misconceptions and restructure their understanding of concepts (Yenilmez and Tekkaya 2006; Vosniadou 2012). Students were given opportunities to reflect on their learning in their Science reflective journals and any misconceptions or misunderstandings were challenged and explored with the teacher in class. If teachers are not given an opportunity to reflect on their teaching and their students’ learning, it is very difficult for them to know what strategies are effective and what information the students understand (Domingos-Grilo et al 2001; Loughran 2002). This forms part of the higher order complex thinking required from teachers and students that promotes conceptual
change and deep understanding of the concepts (Hattie and Timperley 2007). Similar to Kose’s (2008) findings, the misconception that “oxygen is used in Respiration which only occurs in plants when there is no light energy to Photosynthesise” was commonly chosen by the control group (30.5%). In contrast to the experiment group, the control group were not given an opportunity to identify this misconception and tackle it and so it remained with them. Students need to be involved in activities that help them revise their prior knowledge and struggle with their misconceptions (Yenilmez and Tekkaya 2006). It is interesting to note that although there was a significant difference between the mean increments (P=0.003), 30.0% of the experiment group still held misconceptions, leading to the conclusion that misconceptions are deeply rooted and teacher instructional quality plays a significant role in determining students’ outcomes. Even when provided with the lesson guides, students require teachers to play a critical role as translators of these experiences which can be difficult if they hold their own misconceptions (McMillan and Schumacher 2014).

Table 7.3 The number and percentage of students who correctly answered Question 8 in their pre and post-tests for both groups along with the mean scores (pre and post-tests) and the mean increments for both groups.

<table>
<thead>
<tr>
<th></th>
<th>No. of students answered correctly</th>
<th>% answered correctly</th>
<th>Pre-test mean score</th>
<th>p-value</th>
<th>No. of students answered correctly</th>
<th>% answered correctly</th>
<th>Post-test mean score</th>
<th>p-value</th>
<th>Mean increment</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Experiment</strong></td>
<td>69/173</td>
<td>39.9%</td>
<td>0.40 ± 0.49</td>
<td><strong>0.600</strong></td>
<td>150/173</td>
<td>86.7%</td>
<td>0.87 ± 0.34</td>
<td>&lt;0.001</td>
<td>0.47 ± 0.50</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td><strong>Control</strong></td>
<td>65/175</td>
<td>37.1%</td>
<td>0.37 ± 0.49</td>
<td>91/175</td>
<td>52.0%</td>
<td>0.52 ± 0.50</td>
<td>0.15 ± 0.36</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

For question 8, the pre-test mean scores for the experiment group and the control groups were 0.40 ± 0.49 and 0.37 ± 0.49 respectively. There was no significant difference (P=0.600) between the students’ conceptual understandings between the two groups. In the post-test, the mean scores for the experiment and control group were 0.87 ± 0.34 and 0.52 ± 0.50 respectively. The mean scores of the post-tests between the two groups were significantly different (P<0.001). When the pre-tests were compared with the post-tests,
the mean scores for the control group had increased by 0.15 \( \pm \) 0.36, and the experiment group had increased by 0.47 \( \pm \) 0.50. There was a significant difference in the mean increments between the two groups (P\(<0.001\)). The results, therefore, suggest that students from the experiment group had a better conceptual understanding about when green plants respire. The experiment group were provided with everyday examples of Respiration (i.e. experiment with the woodlice; potted plant), the use of everyday life examples in Science teaching improves learners’ enjoyment and aids in their learning (Campbell and Lubben 2000; Lubben et al 1996). In addition, students were given opportunities to investigate what gases were released during Respiration for plants and animals. Organisms were tested for the process of Respiration during the light and dark to help students overcome the misconception that ‘Respiration only occurs in the night’ (Cibik et al 2008). The results indicate that using an inquiry-based teaching practice and having an investigative classroom culture aids in advancing students’ conceptual understanding (Supovitz and Turner 2000). The preparation for science teachers however, to teach in this way can be challenging and time consuming (Sharma and Muzaffar 2012) especially when greater importance is placed on students results in their state examinations than with furthering their understanding (Southerland et al 2007).

Table 7.4 The number and percentage of students who correctly answered Question 10 in their pre and post-tests for both groups along with the mean scores (pre and post-tests) and the mean increments for both groups.

<table>
<thead>
<tr>
<th></th>
<th>No. of students answered correctly</th>
<th>% answered correctly in Pre-test</th>
<th>Pre-test mean score</th>
<th>p-value</th>
<th>No. of students answered correctly</th>
<th>% answered correctly in Post-test</th>
<th>Post-test mean score</th>
<th>p-value</th>
<th>Mean increment</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experiment</td>
<td>82/173</td>
<td>47.4%</td>
<td>0.47 ( \pm ) 0.50</td>
<td>0.396</td>
<td>160/173</td>
<td>92.5%</td>
<td>0.92 ( \pm ) 0.26</td>
<td>&lt;0.001</td>
<td>0.92 ( \pm ) 0.26</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Control</td>
<td>75/175</td>
<td>42.9%</td>
<td>0.43 ( \pm ) 0.50</td>
<td></td>
<td>105/175</td>
<td>60.0%</td>
<td>0.60 ( \pm ) 0.50</td>
<td></td>
<td>0.60 ( \pm ) 0.50</td>
<td></td>
</tr>
</tbody>
</table>

For question 10, the pre-test mean scores for the experiment group and the control groups were 0.47 \( \pm \) 0.50 and 0.43 \( \pm \) 0.50 respectively. There was no significant difference (P=0.396) between the students’ conceptual understandings between the two groups. In
the post-test, the mean scores for the experiment and control group were 0.92 ± 0.26 and 0.60 ± 0.50 respectively. The mean scores of the post-tests between the two groups were significantly different (P<0.001). When the pre-tests were compared with the post-tests, the mean scores for the control group had increased by 0.17 ± 0.38, and the experiment group had increased by 0.45 ± 0.50 and there was a significant difference in the mean scores between the two groups (P<0.001). The results, therefore, suggest that students from the experiment group had a better conceptual understanding about the reactants and products involved in the Photosynthesis equation. As well as carrying out investigations, students in the experiment group took part in role plays (Ross et al 2010), built the chemical structures of the reactants and products involved and used Lego bricks to aid in the balancing of the equation (Ruddick and Parrill 2012) which all proved effective in developing the students’ conceptual understanding of the reactants and products required.

Table 7.5 The number and percentage of students who correctly answered Question 11 in their pre and post-tests for both groups along with the mean scores (pre and post-tests) and the mean increments for both groups.

<table>
<thead>
<tr>
<th></th>
<th>No. of students answered correctly</th>
<th>% answered correctly in Pre-test</th>
<th>Pre-test mean score</th>
<th>p-value</th>
<th>No. of students answered correctly</th>
<th>% answered correctly in Post-test</th>
<th>Post-test mean score</th>
<th>p-value</th>
<th>Mean increment</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Experiment</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>Control</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>86/173</td>
<td>49.7%</td>
<td>0.50 ± 0.50</td>
<td>0.831</td>
<td></td>
<td>143/173</td>
<td>82.7%</td>
<td>0.83 ± 0.38</td>
<td>0.002</td>
<td>0.33 ± 0.47</td>
<td>0.001</td>
</tr>
<tr>
<td>89/175</td>
<td>50.9%</td>
<td>0.51 ± 0.50</td>
<td></td>
<td></td>
<td>120/175</td>
<td>68.6%</td>
<td>0.69 ± 0.47</td>
<td></td>
<td>0.17 ± 0.38</td>
<td></td>
</tr>
</tbody>
</table>

For question 11, the pre-test mean scores for the experiment group and the control groups were 0.50 ± 0.50 and 0.51 ± 0.50 respectively. There was no significant difference (P=0.831) between the students’ conceptual understandings between the two groups. In the post-test, the mean scores for the experiment and control group were 0.83 ± 0.38 and 0.69 ± 0.47 respectively and were significantly different (P=0.002). When the pre-tests were compared with the post-tests, the mean scores for the control group had increased by 0.17 ± 0.38, and the experiment group had increased by 0.33 ± 0.47 showing a significant difference (P=0.001). The results, therefore, suggest that students from the experiment
group had a better conceptual understanding of the factors that are not necessary for Photosynthesis. Students in the experiment group were shown an animation of the factors necessary for Photosynthesis and carried out an experiment to investigate what happened if these materials were in short supply, the teachers then discussed the factors with the students as a group and brainstormed their ideas on the board. All of the above activities have been noted to help students to progress in their understanding of Photosynthesis (Sirinapa 2006).

Overall, the difference between the mean increments of the two groups in part 1 (p<0.001) indicates that the intervention had a significant effect on the students’ conceptual understanding.

7.3: Part 2 of the Identification Instrument - Drawings of Photosynthesis

Part 2 of the identification instrument required students to draw and label a diagram to represent their understanding of the process of Photosynthesis. The students’ drawings were analysed based on four different levels where a higher level (four) reflected a better conceptual understanding (Kose 2008). In the pre-test, an independent t-test showed that there was no significant difference (p=0.432) between the test and the control group prior to instruction.
Table 7.6 The drawings the students drew and labelled to explain the process of Photosynthesis were categorised (Appendix 30) into four different levels (i.e. levels 1-4). The table presents the percentage of students’ drawings per level for the pre-test and post-test.

<table>
<thead>
<tr>
<th>Levels</th>
<th>Pre-test</th>
<th>Post-test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Experiment (n=173)</td>
<td>Control (n=175)</td>
</tr>
<tr>
<td>1</td>
<td>74 (42.8%)</td>
<td>81 (46.3%)</td>
</tr>
<tr>
<td>2</td>
<td>52 (30.1%)</td>
<td>51 (29.1%)</td>
</tr>
<tr>
<td>3</td>
<td>32 (18.5%)</td>
<td>33 (18.9%)</td>
</tr>
<tr>
<td>4</td>
<td>14 (8.1%)</td>
<td>11 (6.3%)</td>
</tr>
</tbody>
</table>

When the pre-test scores from the experiment group and the control group were compared with the post-test scores, it was noted that there was a highly significant difference (P <0.001). The percentage of students in the experiment group whose drawings were categorised as level 1 had decreased from 42.8% to 0% and as level 2 decreased from 30.1% to 13.3%, while the percentage of students with level 3 drawings had increased from 18.5% to 22.0% and level 4 increased from 8.1% to 64.7%. A similar trend was observed in the control group; however a lower percentage of students reached level 3 and 4 of conceptual understanding. For the control group, the percentage of students whose drawings were categorised as level 1 had decreased from 46.3% to 16.0% and increased level 2 from 29.1% to 30.3%, level 3 from 18.9% to 38.9% and level 4 from 6.3% to 14.9%. The percentage of students of each level of Photosynthesis drawings were compared between the two groups in the post-test. Out of the four levels of drawings, all

---

1 No drawing or very poor effort made.
2 Drawings with misconceptions: these drawings showed some conceptual understanding of Photosynthesis but also demonstrated some misconceptions.
3 Partial drawings: the drawings in this category demonstrated partial conceptual understanding of Photosynthesis. The drawings included the sun, water, carbon dioxide, glucose, oxygen and energy in the correct sequence.
4 Comprehensive drawings: these drawings were the most competent and detailed of the four categories and represented a very good conceptual understanding of Photosynthesis. Students identified the reactants and products of Photosynthesis and showed no evidence misconceptions in their drawing and explanation.
were found to be statistically significant (P<0.001) between the experiment and control group. The post-test results of the Photosynthesis drawings indicated a better conceptual understanding of Photosynthesis among the experiment group, as a lower percentage (13.3%) of students were found in levels 1 and 2 and a higher percentage were found in levels 3 and 4 (86.7%) when compared to the control group. Students in the experiment group were taught using a range of concrete visual aids (plants, seedlings, bark, water, light sources, gases), animation (video clips, concept cartoons) and concept maps which may have helped the students to visualise the process of Photosynthesis and the materials required compared to the control group who were taught using a textbook. According to Balim (2013), students that use concept maps understand the subject matter better giving rise to long-lasting. Overall, the results of the students’ drawings on Photosynthesis indicated that students had a better conceptual understanding of Photosynthesis in the experiment group. A significantly higher (P<0.001) percentage of students from the experiment group demonstrated a comprehensive understanding (i.e. level 4) of Photosynthesis. From the results, it appears that knowledge acquisition using a constructivist approach to teaching assures a student centred environment and is more effective in tackling misconceptions in photosynthesis than didactic teaching (Ahopelto et al 2011; Carlsson 2002; Domingos-Grilo et al 2012 Yenilmez and Tekkaya 2006).

7.4: Part 3 of the Identification Instrument – Short Answer Questions

To compare the students’ overall conceptual understanding on the short answer questions, the total score for part 3 (i.e. sum of the ten short answer questions) were compared between the two groups (Table 7.7). For the pre-tests, the experiment group had a total mean score of 4.06 ± 1.2 while the control group had a total mean score of 4.27 ± 1.3. There was no significant difference (p=0.126) between the two groups prior to instruction. In the post-tests, the experiment group had a significantly higher (p<0.001) mean score of
8.62 ± 1.2 compared to the control groups mean score of 5.90 ± 1.1. With a total increment of 4.56 ± 1.7, the experiment had a significantly higher (P<0.001) increase than the control group, which had a total increment of 1.63 ± 1.3.

Table 7.7 The total mean scores and the total increments of the ten short answer questions for the experiment and the control groups

<table>
<thead>
<tr>
<th></th>
<th>Pre-test p-value</th>
<th>Post-test p-value</th>
<th>Total increment p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Experiment</strong></td>
<td>4.06 ± 1.2 0.126</td>
<td>8.62 ± 1.2 &lt;0.001</td>
<td>4.56 ± 1.7 &lt;0.001</td>
</tr>
<tr>
<td></td>
<td>4.27 ± 1.3</td>
<td>5.90 ± 1.1</td>
<td>1.63 ± 1.3</td>
</tr>
<tr>
<td><strong>Control</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

To compare the students’ conceptual understanding on each question, the mean score for each question was compared between the experiment and the control groups. Out of the ten questions, four of these showed a significant difference (p<0.001) from the students’ mean scores between the two groups (refer to Tables 7.8 -7.11). The four questions were questions 2, 4, 6 and 9.

Table 7.8 The number and percentage of students who correctly answered Question 2 in their pre and post-tests for both groups along with the mean scores (pre and post-tests) and the mean increments for both groups.

<table>
<thead>
<tr>
<th></th>
<th>No. of students answered correctly</th>
<th>% answered correctly in Pre-test</th>
<th>Pre-test mean score</th>
<th>p-value</th>
<th>No. of students answered correctly</th>
<th>% answered correctly in Post-test</th>
<th>Post-test mean score</th>
<th>p-value</th>
<th>Mean increment</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Experiment</strong></td>
<td>49/173</td>
<td>28.3%</td>
<td>0.28 ± 0.45</td>
<td><strong>0.606</strong></td>
<td>162/173</td>
<td>93.6%</td>
<td>0.94 ± 0.25</td>
<td>&lt;0.001</td>
<td>0.65 ± 0.48</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td><strong>Control</strong></td>
<td>54/175</td>
<td>30.9%</td>
<td>0.31 ± 0.46</td>
<td></td>
<td>72/175</td>
<td>41.1%</td>
<td>0.41 ± 0.49</td>
<td></td>
<td>0.10 ± 0.30</td>
<td></td>
</tr>
</tbody>
</table>

For question 2 (Table 7.8), question 4 (Table 7.9), question 6 (Table 7.10) and question 9 (Table 7.11), there was no significant difference in the pre-test mean scores for the experiment group and the control groups. There was however, a significant difference (P<0.001) in the post-tests (Table 7.8-7.11). The difference in the mean increment scores between the two groups for questions 2, 4, 6 and 9 were also significant (P<0.001). The results from question 2, therefore, suggest that students from the experiment group had a better conceptual understanding about the importance of plants on the survival of animals.
on earth. 93.6% of the students in the experiment group answered this question correctly compared to 41.1% of the control group. The experiment group participated in a debate on the importance of plants for animals and humans alike. This required students to defend their own view or accept the views of others. This type of argumentation created conflict in some students’ previous perceived concepts which in turn helped to overcome misconceptions (Erduran et al 2004; Syh-Jong 2007). Discussion of concepts can facilitate students’ understanding as well as encourage their conceptual restructuring (Tregust and Duit 2009; Vosniadou 2012). As a result, gradually students become convinced that the scientifically acceptable new conception is more meaningful. In addition, students were taught how to link concepts together (i.e. using concept maps) as it is important for students to be able to relate different concepts to one another and assess how one may affect the other (Partosa et al 2013).

Table 7.9 The number and percentage of students who correctly answered Question 4 in their pre and post-tests for both groups along with the mean scores (pre and post-tests) and the mean increments for both groups.

<table>
<thead>
<tr>
<th></th>
<th>No. of students answered correctly</th>
<th>% answered correctly</th>
<th>Pre-test mean score</th>
<th>p-value</th>
<th>No. of students answered correctly</th>
<th>% answered correctly</th>
<th>Post-test mean score</th>
<th>p-value</th>
<th>Mean increment</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Experiment</strong></td>
<td>45/173</td>
<td>26.0%</td>
<td>0.26 ± 0.44</td>
<td><strong>0.231</strong></td>
<td>151/173</td>
<td>87.3%</td>
<td>0.87 ± 0.33</td>
<td><strong>&lt;0.001</strong></td>
<td>0.61 ± 0.49</td>
<td><strong>&lt;0.001</strong></td>
</tr>
<tr>
<td><strong>Control</strong></td>
<td>36/175</td>
<td>20.6%</td>
<td>0.21 ± 0.41</td>
<td>76/175</td>
<td>43.4%</td>
<td>0.43 ± 0.50</td>
<td>0.23 ± 0.42</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The results from question 4, suggest that students from the experiment group had a better conceptual understanding on what Respiration is. 87.3% of the students in the experiment group answered this question correctly while 43.4% of the students in the control group answered the question correctly. The increased understanding of the concept of Respiration among the experiment group was believed to be due to the same reasons mentioned in question 8 of part 1 of the identification instrument, section 7.2.
Table 7.10 The number and percentage of students who correctly answered Question 6 in their pre and post-tests for both groups along with the mean scores (pre and post-tests) and the mean increments for both groups.

<table>
<thead>
<tr>
<th></th>
<th>No. of students answered correctly</th>
<th>% answered correctly in Pre-test</th>
<th>Pre-test mean score</th>
<th>p-value</th>
<th>No. of students answered correctly</th>
<th>% answered correctly in Post-test</th>
<th>Post-test mean score</th>
<th>p-value</th>
<th>Mean increment</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experiment</td>
<td>45/173</td>
<td>26.0%</td>
<td>0.26 ± 0.44</td>
<td>0.417</td>
<td>146/173</td>
<td>84.4%</td>
<td>0.84 ± 0.36</td>
<td>&lt;0.001</td>
<td>0.58 ± 0.49</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Control</td>
<td>39/175</td>
<td>22.3%</td>
<td>0.22 ± 0.42</td>
<td></td>
<td>70/175</td>
<td>40.0%</td>
<td>0.40 ± 0.49</td>
<td></td>
<td>0.18 ± 0.38</td>
<td></td>
</tr>
</tbody>
</table>

The results from question 6 indicate that students from the experiment group had a better conceptual understanding of how a seedling develops into a tree. 84.4% of the students from the experiment group answered this question correctly in the post-test compared to 40.0% of the students in the control group. The students in the experiment group were given a seedling and a piece of wood from a tree and discussed how the seedling turned into a tree. The students identified the materials required for the seedling to grow; they carried out experiments to see if light, chlorophyll, carbon dioxide, soil, water and oxygen are required for Photosynthesis. These activities and teaching strategies are based on a constructive learning theory which considers students’ previous knowledge and provides them with opportunities to address their misconceptions which is essential for students to learn concepts meaningfully (Marmaroti and Galanopoulou 2006; Sonmez et al 2001).

Table 7.11 The number and percentage of students who correctly answered Question 9 in their pre and post-tests for both groups along with the mean scores (pre and post-tests) and the mean increments for both groups.

<table>
<thead>
<tr>
<th></th>
<th>No. of students answered correctly</th>
<th>% answered correctly in Pre-test</th>
<th>Pre-test mean score</th>
<th>p-value</th>
<th>No. of students answered correctly</th>
<th>% answered correctly in Post-test</th>
<th>Post-test mean score</th>
<th>p-value</th>
<th>Mean increment</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experiment</td>
<td>51/173</td>
<td>29.5%</td>
<td>0.29 ± 0.46</td>
<td>0.365</td>
<td>160/173</td>
<td>92.5%</td>
<td>0.92 ± 0.26</td>
<td>&lt;0.001</td>
<td>0.63 ± 0.48</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Control</td>
<td>44/175</td>
<td>25.1%</td>
<td>0.25 ± 0.44</td>
<td></td>
<td>89/175</td>
<td>50.9%</td>
<td>0.51 ± 0.50</td>
<td></td>
<td>0.26 ± 0.44</td>
<td></td>
</tr>
</tbody>
</table>

The results from question 9, therefore, imply that students from the experiment group had a better conceptual understanding of the materials plants absorb from their environment which was most likely due to the animations they were shown and the opportunities they were given for investigation as mentioned above, when discussing question 6.
7.5: Interview with Pre-service Teachers

After completing the lesson guides with the experiment group, the author interviewed the pre-service teachers to gain an insight into their thoughts on implementing the lesson guides and teaching using a conceptual change approach. As explained in chapter 4, the interview consisted of nine semi-structured questions on the implementation of the lesson guides and seven questions relating to their subject matter knowledge. The subject matter knowledge of the teachers was examined to see if it had an impact on the increase in the conceptual understanding of their students.

7.5.1: Question 1: Why did you offer to implement this Module?

When asked why they offered to implement the module, their responses were similar. They felt the module was appealing and that it was beneficial for them to get an insight into different teaching strategies and resources they could use on teaching practice. In addition they felt that teaching practice is a very busy time and the extra support and help would be useful.

“It seemed interesting.” 
Teacher G

“Having some resources and lesson guidelines already done out would also be helpful to me during my school’s placement as I will be busy coming up with lessons.”
Teacher D

“Having a module for TY’s already prepared would be a big help throughout the placement as I wouldn’t have to come up with new topics and teaching ideas for each TY class.”
Teacher E

Teachers explained that Photosynthesis is a topic that students have great difficulty with therefore; using strategies that would make the material easier to understand and learn would be useful. It is the role of the teacher to improve the deliverance of material and to think of ways that students can learn more effectively (Anderson et al 2001; Bloom 1984).
“Photosynthesis is a topic that students have great difficulty with at leaving cert level as well as Respiration. If it could be made easier or clearer in any way it would be worthwhile. Also the resources that come with this module are fantastic.”

Teacher A

“It is a difficult concept for students to grasp so I was willing to try anything to make it easier.

Teacher C

In addition, the teaching of Photosynthesis has proven to be difficult for many so the resources and innovative teaching strategies would be helpful.

“I felt it would be beneficial to my work as a student teacher as these topics can be quite difficult to teach and I found the resources very helpful and innovative.”

Teacher B

The difficulty of motivating and engaging students in transition year was also mentioned. As transition year incorporates a range of extracurricular activities and the learning of new skills, it can be challenging for students to concentrate and enjoy the academic subjects they are timetabled for during the year (Jeffers 2011).

“I wanted to try this module in an attempt to benefit the learning environment of the students and encourage participation. Another reason is that Photosynthesis is often seen as a boring topic for pupils and one that is deemed difficult. I wanted to try this module to see if it was possible to present this topic as interesting and engaging for pupils.”

Teacher F

7.5.2: Question 2: How did you feel about teaching this Module?

Teachers for the most part were nervous as they knew TY classes are difficult to motivate, some of the teaching strategies they had never implemented in a classroom before and as a result, they felt that the strategies may not be used to their full potential.

“I felt a bit anxious as the specific TY class I was to implement this module to were a rowdy bunch that were hard to motivate. But with this module I felt it relieved the pressure of this.”

Teacher A

“I felt nervous as there were some strategies that I had never used before and I was unsure how to go about implementing them in my classes. I felt that I might not be able to use the teaching methods and resources to their full potential.”

Teacher B
Teachers were worried as some of the students in the class hadn’t studied Science to Junior Certificate level and so wouldn’t have the basics. Senior cycle Biology is a continuation of the material covered in the Biology section of the Junior Certificate Science syllabus (Erduran and Dagher 2014).

“I was nervous because some of the pupils had not studied Science previously and I was worried that their resistance to the topic might have a negative effect on the classroom environment.”

Teacher E

“I was nervous as I wasn’t sure if the pupils would latch on as they might have formed a barrier to engagement before the topic was implemented.”

Teacher C

They expressed a sense of excitement towards the different approach of teaching and confidence in the resources received however, they were anxious that students wouldn’t traditionally be taught in this manner and would not have had to think the way this module expects them to. It is well documented that teachers fear change (Mishra and Koehler 2006).

“I was excited about a different approach to teaching the topic. Generally I would approach this topic with a more traditional style of teaching. I felt confident though with the resources and material provided to implement the module.”

Teacher B

“I was interested to see how the students would respond to Photosynthesis. I was eager to implement it as it included experiments and activities.”

Teacher D

“Very nervous because students most likely would never have experienced anything like this before, and would not have had to think the way this module expects them to.”

Teacher F

7.5.3: Question 3: Did this Module have a positive or negative impact on your Teaching?

All of the pre-service teachers interviewed felt that the module had a positive impact on their teaching. They felt they had learned a number of valuable teaching strategies that were effective in increasing their students’ conceptual understanding of Photosynthesis.
“I got some great ideas of teaching strategies that I have used in my other classes.”
Teacher D

“The students really engaged in the activities.”
Teacher G

“I now have ideas about strategies I can use for teaching the topic in the future”.
Teacher A

They felt more confident in creating engaging and motivating learning environments after implementing the module. Science teachers that participate in Science specific continual professional development are found to be more confident in being innovative in their classrooms and more knowledgeable of their subject matter (Bennett et al 2010).

“With the elevated pressure of coming up with interesting ideas to teach this topic I felt that I was more able to engage with the teaching strategies that were planned.”
Teacher E

“I am not afraid to teach Photosynthesis anymore, I am confident in my ability and subject matter knowledge”.
Teacher B

“I am more confident to move away from the didactic style teaching now, I am less rigid and the students’ information leads the class rather than what I expect the students to know.”
Teacher F

Pre-service teachers did highlight that although this type of teaching is positive it requires a lot of planning and organisation however, effective teaching should always involve rigorous planning (Ladson-Billings 1995).

“I have found that it is difficult to fully implement these lessons as there is so much more work involved.”
Teacher C

**7.5.4: Question 4: Did this Module have a positive or negative impact on your Students’ Learning?**

All of the pre-service teachers felt that the module had a positive impact on their students’ learning. When in class, students were engaged and showed greater understanding of the concepts taught. Using the story cubes to get the students to link the different concepts and the development of the concept map further emphasised the increase in conceptual understanding among the students.
“They appeared to enjoy it more than they usually would.”

Teacher D

They felt that their students could understand the process of Photosynthesis much better than before implementing the module and have a strong basis of knowledge for entering Leaving Certificate Biology.

“The students were very engaged and showed greater understanding after carrying out recap activities using the story cubes and completing the concept map.”

Teacher F

“Students know a lot more about Photosynthesis at this point. I feel that they have a good basis for going into LC Biology as Photosynthesis is a tricky concept to get students heads around.”

Teacher A

For the most part the comments were very positive, however, pre-service teachers did note that it was difficult to keep students motivated. In addition, some students missed a lot of class time due to extracurricular activities, resulting in little improvement in conceptual understanding. As a result, it was suggested that this module was better suited to a fifth or Leaving Certificate class.

“I did find that there were some problems with student motivation during this module. The students are in transition year and were often absent from class which meant that it was very difficult to have consistency throughout the module. Furthermore, I feel that this module would be better suited to a Leaving Cert Biology class where the students are more focused and are required to study Photosynthesis as part of the syllabus.”

Teacher B

“I found that some students were disengaged and lacked motivation when they were studying the topic of Photosynthesis.”

Teacher E

“Although some students were constantly absent taking part in extracurricular activities and showed little progress due to this fact, the others engaged with the ideas and tasks and pupils certainly showed increased levels of understanding on the topic of Photosynthesis.”

Teacher C

In addition, one teacher felt it was far too difficult for the students she was teaching and found they really didn’t have the basics from Junior Certificate Science which was and still is a significant problem.
“It was far too difficult for them which was and is a massive problem. But they did advance on their knowledge in a more interesting way.”

Teacher G

7.5.5: **Question 5: What have you learned about yourself as a Teacher after completing this Module and Teaching using a Conceptual Change Approach?**

All seven teachers that were interviewed felt they had learned something about themselves and their teaching after completing the module.

“I have become more confident in my approach to the use of different teaching strategies. As we do not have specific modules on how to teach or modules on strategies to increase student understanding I felt this gave me the tools to use these strategies in other lessons.”

Teacher A

It is encouraging to hear such comments from pre-service teachers. These comments reinforce the pre-service teachers’ need and desire to have pedagogy modules that teach them how to teach using a conceptual change approach and the importance that should be placed on the awareness of misconceptions and the affect they can have on students’ learning if not addressed effectively.

“I have learned that I sometimes rely on a more chalk and talk type of teaching style to convey more difficult concepts to the students. By carrying out this module I have learned that the students respond well and show a greater understanding of a topic when I use the conceptual change methods”.

Teacher B

This is not a surprising statement to make as a didactic approach to teaching is very common in Ireland (Forfás 1999) especially when teaching an abstract topic like Photosynthesis because it is the only way they know how. Traditionally, “good teaching” was portrayed as having good ‘control’ and getting the material ‘covered’ (Sugrue 1996). Traditional teaching using a didactic, teaching centred approach is insufficient for correcting students’ misconceptions (Abraham *et al* 2009).

“Rather than just telling the students the information, students showed a greater depth of understanding when they overcame misconceptions themselves by going through concept cartoons”.

Teacher C
It is evident that this teacher has realised and witnessed first-hand the effect that addressing misconceptions can have on the advancement of students’ learning.

“I have learned that I must not become complacent about my approach. I must accept new challenges and change my approach accordingly.”

Teacher D

“I learned that it is an awful lot of work and incredibly difficult to plan for this type of teaching all the time. I also learned that my classroom management needs work. I need a lot more practice before I would consider myself competent at teaching in this way”.

Teacher G

It is apparent that Teacher D and G found this type of teaching difficult but appreciated the importance of reform (Levin 2000) and realised the significance this change in teaching style had on their students’ learning. Johnston (2009) believes that there is opportunity for greater professional satisfaction through enhanced student learning and active engagement with it. Science needs to intrigue teachers and students; therefore it needs to be taught in a stimulating, imaginative and creative way using multiple pedagogical approaches including professional dialogue and co-inquiry (Mooney Simmie 2007). A shift towards a more interactive and collaborative professionalism is essential (Sugrue and Thuama 1997). All of these new pedagogical approaches will challenge teacher educators as well as teachers and their students (Bryant et al 2001; Duncombe and Armour 2004; Young et al 2015).

“As a teacher, I now realise the importance of being aware of the diversity in the classroom. It is important to keep this in mind when structuring group work, learning outcomes and topics being discussed to ensure a positive learning experience for all pupils. Through teaching this module, I also am now more aware of the importance of identifying misconceptions when teaching. This enhances the learning experience for all and also assists with pupils’ in depth understanding of the topic”.

Teacher E

“I think that creativity is key and that students respond well to physical models and as many examples to real life as possible”.

Teacher F

Students find it easier to relate to concrete material when discussing abstract content, using models to help students comprehend the information is invaluable to their
understanding (Harrison and Treagust 2000). In addition, relating Science to their everyday life (Sikoyo and Jacklin 2009) overcomes the idea which many students hold that Science is a “foreign” subject.

7.5.6: Question 6: Did you Identify Misconceptions while Teaching? (If so please state)

The pre-service teachers identified a number of misconceptions that they addressed with their students while implementing the module. See Table 7.12 for the list of misconceptions identified.

Table 7.12 List of misconceptions that students held in Photosynthesis and Respiration in Plants identified by Pre-service teachers who taught the experiment group the TY module

<table>
<thead>
<tr>
<th>Misconceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water, sunlight and carbon dioxide are ‘food’ for the plants.</td>
</tr>
<tr>
<td>Plants do not carry out Respiration or that there is no link between Respiration and Photosynthesis.</td>
</tr>
<tr>
<td>Plants breathe in carbon dioxide and breathe out oxygen.</td>
</tr>
<tr>
<td>The only source of light for plants is sunlight.</td>
</tr>
<tr>
<td>Sunlight provides heat to the plant to carry out Photosynthesis.</td>
</tr>
<tr>
<td>Plants store their food as glucose and not as starch.</td>
</tr>
<tr>
<td>Plants release all of the oxygen they produce and none is used for Respiration.</td>
</tr>
<tr>
<td>The rate of Photosynthesis can continue to increase if light intensity increases and that there are no limiting factors.</td>
</tr>
<tr>
<td>Plants get their food from water, minerals or the soil.</td>
</tr>
<tr>
<td>Water is food for plants.</td>
</tr>
<tr>
<td>Plants get their food from the soil via the roots.</td>
</tr>
<tr>
<td>Plants breathe by inhaling carbon dioxide and exhaling oxygen.</td>
</tr>
<tr>
<td>The sun warms the plant and provides the plant food.</td>
</tr>
<tr>
<td>Plants can make their food at any time.</td>
</tr>
<tr>
<td>Glucose is the main product of Photosynthesis.</td>
</tr>
<tr>
<td>Plants Photosynthesise and animals respire.</td>
</tr>
<tr>
<td>Plants don’t respire.</td>
</tr>
<tr>
<td>Plants respire during the night only.</td>
</tr>
<tr>
<td>Students often believed that carbon dioxide only enters the plant through the leaves.</td>
</tr>
<tr>
<td>Many think that plants breathe by inhaling carbon dioxide and exhaling oxygen.</td>
</tr>
<tr>
<td>Photosynthesis takes place in the leaves only.</td>
</tr>
</tbody>
</table>

The misconceptions that were identified were in relation to the timing of Photosynthesis and Respiration, what the reactants and products are and where they are sourced,
Respiration being synonymous to breathing, heat energy being a requirement for Photosynthesis and the belief that Photosynthesis only occurs in the leaves of the plant. All the misconceptions in Table 7.12 were already identified by previous researchers as common misconceptions among second level students as highlighted in Chapter 3.

7.5.7: Question 7: What Teaching Strategies did you find most successful in Identifying Misconceptions?

Similar to researchers (Ekici et al 2007; Keogh and Naylor 1999; Stephenson and Warwick 2002), the pre-service teachers felt that concept cartoons were very successful in identifying their students’ misconceptions. Effective imagery is seen as an important element in aiding the process of identification and overcoming (Kici 2012).

“The visually appealing images proved to divide people’s opinions which gave space for discussion and teasing out prior knowledge and misconceptions”

Teacher B

“I found concept cartoons to be a very useful technique to help students identify and overcome their misconceptions. The students analysed and discussed the cartoons and then came to the realisation themselves that their previous ideas weren’t fully accurate.”

Teacher D

“The cartoons were a huge benefit. I had not seen these before and they were very effective during lessons.”

Teacher E

Teachers A and F also found other strategies and resources helpful for the identification of students’ misconceptions.

“A lot of the strategies were extremely beneficial in identifying misconceptions in particular the Science reflective journals, the concept maps, the experiments, lego bricks and concept cartoons.”

Teacher A

“Think pair share activities were good to identify these as students would share their thoughts with each other rather than say them out loud in class.”

Teacher F

The Lego bricks were used in balancing the reactants with the products of Photosynthesis. Assigning a coloured Lego brick to each element helps in the development of the chemical structure and balancing process (Ruddick and Parrill 2012). Think, pair, share activities
allow for classroom discussion which increases the students’ knowledge, tackles misconceptions and improves their understanding (Boston 2002).

**7.5.8: Question 8: What Teaching Strategies did you find most successful in Overcoming Misconceptions?**

Consistent with findings from Kose (2007) and Tekkaya (2003), the majority of teachers found that the concept map was one of the best strategies at overcoming misconceptions in Photosynthesis. In addition, it is well documented that students’ ideas are brought nearer the scientific ideas when they are constructing a concept map together in small groups (Westman 2013).

“Pupils’ creation of the concept map using the images and creating sentences. Pupils could visualise the two separate processes and move the pictures around until they were happy with what they had created.”

Teacher A

“the concept map to be an extremely successful teaching strategy as the students could link all the different elements of Photosynthesis together. As they only had one card for each blank the students needed to figure out which cards fit in where and therefore they could overcome any misconceptions that they still held about the topic.”

Teacher C

“The concept map worked great.”

Teacher F

The concept map is a very effective strategy to explain and show how the different concepts relate to one another. If students continue to learn concepts separately their conceptual understanding will remain at the knowledge level whereby students merely remember facts of information. Teachers need to strive for their students to reach higher levels of Bloom’s Taxonomy were they are able to analyse and evaluate the importance of the concepts taught (Anderson et al 2001; Partosa et al 2013).
Teachers B and D found the story cubes to be another successful strategy at overcoming misconceptions. Story cubes have been found to be effective in linking different concepts within the overall topic (Hiebert 2013).

“The students found the light and the dark stage to be quite difficult but when they used the story cubes to tie together the different aspects, the students began to see how the processes work and the role that each element plays.”

Teacher B

“The story cubes worked really well.”

Teacher D

Teachers E and G found group work, class debates and carrying out experiments equally beneficial at tackling misconceptions.

“Group work and class debates were most effective in overcoming misconceptions.”

Teacher E

“Doing the experiments really helped too.”

Teacher G

Science lessons which elicit debate and argumentation appear to enable students to experience phenomena that will contradict their previous beliefs and induce conceptual change (Erduran et al 2004; Pine et al 2001; Valanides 2000).

7.5.9: Question 9: Did you find the Website Resource a valuable tool for your Teaching?

Six out of the seven teachers interviewed agreed that the website was a useful resource however, Teacher G felt

“it wasn’t incredibly useful, I felt there needed to be more examples of lesson plans and video clips.”

Teacher G

“I found the misconceptions section very useful for all classes.”

Teacher A

“The lesson plans had some very good ideas for introducing and developing classes outside of the TY group.”

Teacher C

Teachers B and D found the literature section of the website a useful resource.
“The literature was sectioned into different topics in the teaching strategies section which made assessing the information really easy.”

Teacher B

“I found the literature links to be useful as we have reflections to write every week and I could refer to these when I was looking back on my lessons.”

Teacher D

“There are also really useful class tests done out and also easy access to the Leaving Cert Biology syllabus, exam papers and marking schemes all in the one place. The website is really easy to use and has a clear layout.”

Teacher E

“Yes as it provided another resource and more innovative teaching strategies to use if others were not working with the class.”

Teacher F

For the most part, the pre-service teachers regarded the website as a useful resource to their teaching. To address Teacher G’s comment, the author must look at providing more beneficial video clips and sample lesson guides. The usefulness of the website is evaluated in greater detail in chapter six.

7.6: To Examine the Subject Matter Knowledge of the Pre-service Teachers

Students’ understanding of the concepts depends hugely on how their teachers implemented the lesson guides, if the teacher is more willing to change his or her teaching practices it has a greater effect on the powerfulness of the learning (Sirinapa 2006). Although every attempt was made to reduce the variables between the groups (chapter 4) the subject matter knowledge and pedagogical content knowledge of each individual teacher will vary, therefore the author examined the pre-service teachers’ subject matter knowledge of Photosynthesis in case the students’ advancement in conceptual understanding was restricted due to their teacher’s adequate subject matter knowledge. The literature review already revealed a large number of studies that identified a problem with the content knowledge (subject matter knowledge) of teachers (experienced teachers and pre-service teachers) and the need for this to form part of a new and innovative effort in relation to initial and continuing education of teachers (Abell 2008; Luera et al 2005; Sullivan-Watts et al 2013).
Question 1: Choose the correct answer to the following questions:

a) Where in plants does Photosynthesis take place?

b) Where in plants is chlorophyll located?

c) Where in plants are chloroplasts located?

Pre-service teachers were asked to choose the correct answer to parts a, b and c. All parts to question 1 were multiple choice questions. All of the pre-service teachers interviewed answered parts a, b and c of question 1 correctly by choosing all green parts as their answer to all three parts. They explained their reason for their choice as Photosynthesis occurs within any cell that contains chlorophyll and chlorophyll is the green pigment (Clegg 2011). The most common misconception here that is found to be prominent among students is that Photosynthesis only occurs in the leaves of the plant (Boomer and Latham 2011; Marmaroti and Galanopoulou 2006). As mentioned in the Literature Review in chapter 3, the representations in textbooks used by teachers have contributed to this belief as they emphasise only the leaves of the plant carry out Photosynthesis (Angell et al 2005; Gilbert and Watts 1983; Griffiths and Preston 1992; Kose et al 2009).

Question 2: When does Photosynthesis take place? (Choose the correct answer)

Figure 7.1 represents the pre-service teachers’ conceptual understanding of question 2, 86% of the pre-service teachers’ interviewed answered question 2 correctly and 14% held a misconception.
Six (86%) out of the seven pre-service teachers answered this question correctly by choosing ‘Photosynthesis takes place where there is light’. Any time there is light (natural or artificial) present the plant will undergo Photosynthesis. A common misconception is that Photosynthesis only occurs during the day therefore the person isn’t considering artificial light. When the author observed the pre-service teachers teaching this, three of the seven pre-service teachers portrayed this misconception to their students. However, when asked the question in the interview they answered it correctly. The inappropriate use of language when explaining it to their students contributed to the development of such a misconception (Clerk and Rutherford 2000; Kindfield 1991). Interestingly this misconception wasn’t the answer chosen by the pre-service teacher who answered incorrectly during the interview; the incorrect answer chosen was ‘Photosynthesis takes place continuously’. Very likely the pre-service teacher confused the process with Respiration as Respiration occurs continuously.

**Question 3: Do plants need light to live and grow? (Choose yes or no and explain your answer)**

All teachers agreed with this statement and explained that light is necessary for plants to live and grow as light is essential for Photosynthesis and without Photosynthesis the plant wouldn’t have any food to live and grow. A common misconception here is that if a plant is in the soil they will still live and grow without light as the soil will provide them with “food” (Marmaroti and Galanopoulou 2006).
Question 4: A bean plant needs energy for Photosynthesis. Where does that energy come from? (Check all that apply)

![Pie chart showing 57% correct and 43% misconception]

Figure 7.2 represents the pre-service teachers’ conceptual understanding of question 4, 57% of the pre-service teachers interviewed answered question 4 correctly and 43% held a misconception.

Four (57%) out of the seven pre-service teachers answered this question correctly by choosing the sun. The other three (43%) teachers believed that air and water provided the plant with energy. This is a common misconception among students and teachers that the plant’s energy comes from multiple sources such as air and water (Yee 2012). This could have contributed significantly to the advancement of students’ conceptual understanding in post-test scores (Yip 1998). Students who are taught by teachers who are knowledgeable in their subject matter and practice a variety of active methodologies within their classroom exhibit an understanding of the concepts targeted in instruction that is more integrated, more coherent and at a higher level of abstraction than the understanding achieved by other students (Hattie 2003).

Question 5: Which of the following processes occurs in a seed during germination?

All seven teachers answered this question correctly; however some of their reasoning could be improved. For example, Teacher F’s response was “Seeds will use energy to develop”. This doesn’t explain anything about the processes that occur in a seed during
germination. A more in-depth explanation should have been provided which further emphasises the inadequate subject matter knowledge of some of our pre-service teachers in their final year of their initial teacher training. Plants use the energy stored within the sugars of the seed to germinate and grow until it reaches the surface, at which point Photosynthesis takes over as the leaves have access to light energy. A common misconception is connecting Photosynthesis to plant growth and may not take into account that there is no sunlight under the soil so plants must use an alternative energy source during germination (Boomer and Latham 2011).

**Question 6: What effect does Photosynthesis have on carbon dioxide in the atmosphere?**

![Circle graph showing 86% Correct Answer and 14% Held Misconception]

**Figure 7.3 represents the pre-service teachers’ conceptual understanding of question 6, 86% of the pre-service teachers’ interviewed answered question 6 correctly and 14% held a misconception.**

Six (86%) out of the seven pre-service teachers answered this question correctly; Photosynthesis decreases the carbon dioxide in the atmosphere because plants use carbon dioxide from the atmosphere during Photosynthesis. Teacher G stated that the carbon dioxide level in the air wouldn’t be affected as the carbon dioxide didn’t come from the air it came from the soil. This is the third example of how teachers hold their own misconceptions even after three years studying Biology at undergraduate level; the
findings are parallel with Gil-Perez and Carrascosa (1990). Teachers have the potential to contribute significantly to the formation of students’ misconceptions (Garnett et al 1995; Liu and Mingyu 2012).

**Question 7:** A plant’s body mass is made up of carbon-based molecules. Where does that carbon come from?

![Figure 7.4](image)

**Figure 7.4** represents the pre-service teachers’ conceptual understanding of question 7, 86% of the pre-service teachers’ interviewed answered question 7 correctly and 14% held a misconception.

Six (86%) out of the seven teachers answered this question correctly choosing air while Teacher G chose D; soil. The pre-service teacher believed that plants use carbon in organic matter in the soil during Photosynthesis. The results obtained from the seven questions addressing the pre-service teachers’ conceptual understanding of Photosynthesis even after being taught the topic using a conceptual change approach further emphasised how deeply rooted misconceptions can be and how long they can take to tackle and overcome. Misconceptions cannot be changed by providing the individual with the correct answer. They need time to develop reasoning as to why their belief is not valid (Taber 2000).
7.7: Summary of key findings from the Interviews

Overall, the majority of the pre-service teachers answered the questions correctly and showed a high level of understanding of Photosynthesis and Respiration in plants. However, Teacher G answered 3 out of the 7 questions incorrectly which may have contributed to Teacher G’s students not advancing as much from their pre-test to post-test scores. A p-value of 0.675 indicated however, that there was no statistical significant difference between the students’ post-test scores taught by Teacher G and the other experiment group students.

Science professional development needs to address teachers’ needs as learners along with building on their current existing knowledge of science content, teaching, and learning (Burgoon et al 2011). If Science teachers are placed with the responsibility of eliminating such misconceptions held by their students, it is imperative that they are provided with the necessary conceptual toolkit to do so (O’Grady et al 2014). One of the first reasons noted in the interviews for participation in this intervention was it would provide the pre-service teachers with extra help and support. It has been well documented that support structures are essential for teachers to thrive in the classroom; unfortunately in many schools teaching can feel very isolated at times (Darling Hammond 1995). Researchers have reported that participation in induction programmes influenced their development as professionals (Gold 1996; Luft et al 2002). Where possible induction programmes should be collaborative efforts between teacher education programmes in universities and local schools (Watson 2006). Universities should take more responsibility for supporting and providing resources for their graduates (Kelley 2004; Odell and Ferraro 1992). In addition, similar to Treagust and Duit’s (2009) findings, it is not only the cognitive domain of the individual that needs to be nurtured but the holistic development; pre-service teachers expressed feelings of anxiety; they were worried and nervous about teaching.
To ensure successful implementation, there is the need for teacher education institutions to incorporate the teaching of content analysis techniques into their programs. Adequate knowledge of how to analyse subject-matter content is necessary for good pedagogical planning and instruction (Abell 2008; Abimbola and Baba 1996; Özmen 2004). Science teachers who have this competence and capacity will be able diagnose, reduce and remediate misconceptions and alternative conceptions, thereby preventing them from becoming a source of accurate knowledge for their students (Abimbola and Baba 1996). To be effective in diagnosing, reducing and rectifying teachers' misconceptions and preventing these being propagated, teacher education programmes need to equip Biology teachers with the necessary knowledge and skills to use textbooks more critically and selectively, and to be alert to the inaccurate information described in textbooks as it is known to be a most significant tool a teacher has while teaching (Yip 1998).

Teacher education programmes need to aim at promoting the awareness of teachers to students learning difficulties and developing their professional skills in facilitating students conceptual development. The pre-service teachers noted that they found photosynthesis a difficult topic to understand themselves and teach appropriately and found themselves resorting to a didactic approach when teaching difficult aspects of the topic. According to the National Science Education Standards, the most important resource is professional Science teachers when evaluating Science education programmes (Lumpe 2008). What teachers do in a classroom matters immensely, if teaching is indeed the most critical factor in student learning, then teacher preparation and continuing professional development stands to play a huge role in impacting student achievement (Marzano et al 2001). Although the identification of misconceptions is an important initial step towards better science teaching and learning, knowledge of the causes and processes
of development of such informal views is essential for designing and constructing
effective pedagogical strategies that aim to prevent, reduce or rectify misconceptions
within a ‘good enough’ model of teaching (Kose 2008). All of the new pedagogical
approaches will challenge teacher educators as well as teachers and their students (Bryant

In Ireland, the subject content knowledge in CPD courses is often more examination
focused than learner centred (Mooney Simmie 2007), teachers are merely being “coached
to the exams” and to rote learning and memorisation (Gleeson 2012). Long-term
professional development programs are clearly needed to achieve lasting changes in
teachers' specialist knowledge base. Teacher education should not end with qualification;
induction programs with a multiplicity of policy actors are essential in addressing the
pedagogical, professional and content needs of Biology teachers (Luft et al 2003). Indeed,
critical pedagogical reflection about teaching and learning has to become an integral part
of teachers’ continuing professional development (Domingos-Grilo et al 2012; Penso et al
2001). Teachers need a deeper understanding of learners’ misconceptions in order to
realise the importance of this area of practice. The identification of misconceptions in
Biology, and for topics such as, photosynthesis, is essential for misunderstandings and
misconceptions to be addressed and for learning to be developed and advanced (Hodgson
and Pyle 2010). Teachers that are aware of common prior ideas and misconceptions will
be better able to help students open their mind to new experiences and cognitive
development (Driver et al 2014). It has been argued that contemporary society needs
students that are creative thinkers capable of becoming critically engaged in an area of
science they enjoy; however students have become experts at passively consuming
knowledge rather than actively generating it (Hennessy et al 2011). Teachers clearly need
encouragement and support in order to become committed to changing practices and
possess a willingness to try new ideas that may enhance their teaching and student learning (Tamir 2004; Young et al. 2015). A shift towards a more interactive and collaborative professionalism is essential (Sugrue and Thuama 1997).

To conclude, the pre-service teachers were found to still hold misconceptions themselves even after specific teacher education and training which emphasises that misconceptions can be deeply rooted and conceptual change takes time and is a gradual process of restructuring concepts. On a positive note, all of the pre-service teachers identified misconceptions among their students which is an important initial step in the right direction.
Chapter 8: Discussion

8.1: Introduction

This chapter looks at the key findings from the three phases of the research. Elements of the three phases of results are brought together and discussed in the context of the research questions. New knowledge from the study is explored along the lines of a ‘good enough’ model of science teacher education.

8.2: To what extent do senior cycle students, pre-service and qualified teachers hold misconceptions in Biology and what misconceptions are the most prevalent?

Results from the identification instrument (chapter five, phase one), the evaluation of the additional pedagogy (chapter six, phase two) and interviews with pre-service teachers (chapter seven, phase three) are drawn upon to answer this question. All three groups of participants were found to hold misconceptions in this study, which was in line with the literature reviewed (Park and Slykhuis 2005; Sheehan 2010; Yip 1998). A one-way Anova showed that there was a highly significant difference (p<0.001) between the mean percentage of misconceptions held between the three groups. Although the mean percentage of misconceptions decreased considerably with increasing level of education the percentage of misconceptions held among pre-service teachers in their second and third year of study and qualified teachers is indisputably high. These results indicate that misconceptions are resistant to change (Smith et al 1993; Sundberg 2003) and they persist from each level of education to the next (Kapyla et al 2009; Krall et al 2009; Novak 1987; Partosa et al 2013; Yip 2007).

When the pre-service teachers were interviewed after completing their teaching practice the additional misconceptions were noted among three out of the seven teachers interviewed.
- Plants use carbon in organic matter in the soil during Photosynthesis.
- The carbon dioxide level in the air is affected by Photosynthesis as the carbon dioxide doesn’t come from the air it came from the soil.
- Photosynthesis takes place continuously.
- Air and water provide the plant with energy.

The comments “I didn’t realise I had so many misconceptions”, “I am glad I have identified some of my own misconceptions before TP”, “I have learned that I have transferred some of my own misconceptions on to students during my second year teaching practice” were also recorded in the evaluation form completed after the additional pedagogy module. 13.73% of the pre-service teachers that completed the evaluation form (chapter six, phase two) said that the module identified some of their own misconceptions, adding further support to the findings that teachers possess misconceptions of their own.

The results from this study are parallel with national (Butler et al 2014) and international studies (Abell 2008; Luera et al 2005; Sullivan-Watts et al 2013). Misconceptions are found among students at primary (Mikkila-Erdmann 2000), secondary (Boomer and Latham 2011; Yenilmez and Tekkaya 2006) and university levels (Ross et al 2010; Russell et al 2004), as well as among the pre-service (Brown and Schwartz 2008; Carlsson 2002; Parker et al 2012) and service primary and secondary school teachers (Kapyla et al 2009; Krall et al 2009; Partosa et al 2013; Yip 2007). It is essential to recognise the importance of teachers in the development of students in schools (Lynch and Lodge 2002). A clear link was observed between the misconceptions present in pre-service and service teachers’ knowledge base and those dominant in students (Yip 2007). Studies show that science teachers need effective ways to confront their own misconceptions before they can effectively assist their students in this regard (Allen 2014; Burgoon et al 2011; Lim and Lee 2014; Yip 1998). However, many teachers, due to the demands of curriculum and time constraints are compelled to seek short cuts and do not pay sufficient attention to students’ misconceptions (Chen et al 2006).
From studying the chief examiners reports and findings from international studies the most prevalent topics that participants held misconceptions in were Photosynthesis, Cellular Respiration, Diffusion, the Cell Cycle, the Circulatory System, Ecology, Genetics and DNA. The identification instrument which was distributed at the start of the investigation tested the presence of misconceptions among these topics. When the ten years of state examination papers were reviewed it was found that all the topics that were examined in the identification instrument were common topics to appear in the senior cycle Biology examination paper. It was noted that Photosynthesis, Respiration, Ecology and Genetics appeared on the higher level Biology paper every year. The Circulatory system was questioned six out of the ten years and the Cell cycle and Diffusion were examined four out of the ten years (State Examinations Commission 2014). As these topics appear regularly on the senior cycle examination and as teachers in Ireland tend to teach to the exam one would expect that students and teachers would have a good understanding of these topics however, there was no significant link found (P=0.466) between the percentage of misconceptions held and the grade participants got in their state examination, which really questions the reliability of the exam at testing students’ understanding.

This is evidently a worrying trend which suggests that Irish senior cycle students have an insufficient understanding of Biological concepts. This is despite the high level of honours grades achieved by senior cycle Biology students where the percentage of students achieving an honours grade (A, B or C) from 2006 to 2013 remained consistently above 70% (State Examinations Commission 2006-2013). These grades would seem to suggest a good level of understanding of Biological concepts, which is greatly in contrast with the
findings of this study. Although the results of this study cannot be confirmed to conform to the remainder of Irish senior cycle students, it suggests that the model of testing used to assess senior cycle Biology students does not accurately display their level of understanding. This has been confirmed throughout the literature with Irish senior cycle Biology examinations largely being associated with the regurgitation of facts as opposed to understanding of information (Gleeson 2012; Hennessy et al 2011).

From the results obtained from all three phases of the study there is no doubt that misconceptions are an issue among students and their teachers in senior cycle secondary education in the Republic of Ireland, and particularly in the area of photosynthesis, and need to be supported and scaffolded in multiple ways into the future. Other studies have show that teachers have been found as direct contributors of misconceptions in other studies (Donovan and Bransford 2005; Yip 2007). Without tackling these misconceptions using a number of broad-based approaches students, and their teachers, will continue to find it very difficult to progress and advance their conceptual understandings (Gooding and Metz 2011).

8.3: How can conceptual change be incorporated effectively in the Science classroom?

Science teacher education in the Republic of Ireland has traditionally focused on subject matter content knowledge in the sciences, and that is often content knowledge that is factual and lower order and not rich with concepts and abstractions, in preference to eliciting discussion in relation to achieving an effective learner centred classroom. According to (Diakidoy and Iordanou 2003) in order to implement conceptual change, it is imperative for the teacher to first recognise the extent of the ‘problem’. It is evident that pre-service teachers in this study were underestimating the critical nature of the ‘problem’
of students’ misconceptions, also observed by (Burgoon et al 2011). Studies suggest that all teachers need to find appropriate ways to recognise and confront their own misconceptions, and become supported in this regard in teacher education programs, before they can effectively assist students (Burgoon et al 2011). Therefore, in order for teachers to implement conceptual change strategies with their students, it appears they themselves need to possess a high standard of disciplinary content knowledge and a high degree of awareness of each individual student’s misconceptions (Gomez-Zwiep 2008).

It can be difficult for science teachers to implement effective active learning strategies in this regard without themselves engaging in a multiplicity of educative opportunities, such as, dialogue, reflective practice, argumentation, meaningful guidance, and access to research literature (Keys and Bryan 2001). Science teacher higher education programs need to interrupt the cycle of misconceptions and proactively assist pre-service teachers develop effective practices to identify, reduce and improve the probability of eliminating misconceptions (Asay and Orgill 2010; Driver et al 2000). Teachers need to be aware of what conceptual change is before they can aid in its implementation in the classroom, it is well documented in chapters 2 and 3 that conceptual change is a very slow and gradual process; it is not just the cognitive domain; the affective and motivational factors have an important role in conceptual change (Treagust and Duit 2009) and is significantly influenced by social, historical and contextual processes (Hatano and Inagaki 2003; Taber 2009). Therefore, it is important that a positive and inclusive classroom environment is created.

During phase two a number of the conceptual change strategies were explored in the additional pedagogy module. The strategies were found to successfully identify some of
the misconceptions pre-service teachers didn’t realise they possessed. Within the module the following strategies were incorporated; refutation text/conceptual change text, analogies, concept maps, concept cartoons, models and argumentation dialogue through debate. Depending on the pre-service teachers’ learning styles and preferences certain strategies appeared to better scaffold them in this regard. The majority of the pre-service teachers found using a visual image/aid more beneficial in identifying and tackling misconceptions. Many found the analogies difficult to comprehend which was noted in the literature that analogies can have the opposite effect if not understood fully (Clement and Brown 2004). In the evaluation form, it was evident that concept maps and concept cartoons were the most preferred strategies by far for the pre-service teachers.

Teachers who came on-line and joined the Biology website found that the website was a useful resource and conceptual tool that could help promote conceptual change in the classroom. Within the interviews, the pre-service teachers praised the different sections of the website with a particular emphasis on teaching strategies. They commented on the ease of navigating from one section of the site to the other and the benefits the literature links and lists of common misconceptions per topic had on their teaching practice. 84% of the members when completing the evaluation form either agreed or strongly agreed that the website was a useful resource for their teaching. 36% of the cohort said they accessed the website once a week to assist in their initial teacher education or teaching. 95% of the members either agreed or strongly agreed that they would recommend the resource to other Science teachers. It is also evident from the blogs posted on the website that pre-service teachers and qualified teachers are enjoying and making use of the resource.
Pre-service teachers also became aware of the benefits of consulting with their students to ensure the progression of their learning. The importance of questioning and challenging their students’ understanding was brought to the forefront in the module; emphasising the prior knowledge of students should not be taken for granted (Ruddock 2002). Once their students’ misconceptions are recognised and diagnosed, teachers need to provide multiple opportunities in the classroom for students to confront misconceptions for their reduction and possible elimination through reconstructing new scientifically accurate conceptual knowledge (National Research Council 1997; Modell et al 2005).

In relation to phase three, during the interviews with the pre-service teachers they were asked to identify the strategies which they found most effective in identifying and overcoming misconceptions among their students in the classroom. Similar to other research studies (Ekici et al 2007; Keogh and Naylor 1999; Stephenson and Warwick 2002), the pre-service teachers felt that concept cartoons were very successful in identifying their students’ misconceptions. The Lego bricks were also highlighted as a worthwhile strategy to use when balancing equations and aided numeracy (Ruddick and Parrill 2012). Placing students in small groups for discussion on a concept using refutation text increased the students’ knowledge, as it created dissatisfaction, tackled misconceptions and improved their understanding (Boston 2002). Consistent with findings from Kose (2007) and Tekkaya (2003), the pre-service teachers found that the concept map was one of the best strategies to help overcome misconceptions. Concept maps are a very effective strategy to explain and show how the different concepts relate to one another. If students continue to learn concepts separately their conceptual understanding will remain at the lower knowledge level whereby students merely memorise facts of information (Anderson et al 2001; Partosa et al 2013). Teachers found the story cubes to be another successful strategy at overcoming misconceptions (Hiebert 2013). Many
teachers reported that they incorporated debate in their classes, it is well documented that Science lessons which elicit debate and argumentation appear to enable students to experience phenomena that will contradict their previous beliefs and induce conceptual change (Erduran et al 2004; Pine et al 2001; Valanides 2000).

Teaching using activities mentioned above encourage discovery learning (Bennett 2003), problem based learning (Savery and Duffy 1995), active learning (Kyriacou 1998; O’Grady et al 2013) and context based learning (Campbell and Lubben 2000), all of which has positive implications for improving students’ conceptual understanding of Biology (Johnstone 2000; Reid 2008). Providing teachers with the opportunity to engage in CPD specific to their subject area in order to develop their subject matter knowledge and engage in pedagogical practices that go beyond mere instruction are found to be effective in challenging and advancing students’ conceptual understanding of specific topics within the syllabus is desirable (Biesta and Miedema 2012). CPD has been found to empower and motivate teachers about their work. Furthermore, CPD is vital if the status and profile of the teaching profession is to be maintained, and developed in the future (O’Flynn and Kennedy 2000).

An Irish study funded by the NCCA investigated what helps students to learn; the results showed that it was vital for students that the teacher explains the content clearly and slowly, students found that an informal climate in the classroom was favourable. Another important factor stated by the students was an intrinsic interest in the subject for both the teacher and student has a positive impact on the value of teaching and learning. Only a minority of the students that participated in the study described a more traditional ‘chalk and talk’ method as helping them to learn (Smyth et al 2006).
Overall, the findings from this study showed that the two diagnostic test instruments were relatively easy to design and administer and were able to reveal the levels and types of misconceptions. They could be adapted and become an entry point into a pedagogical cycle, of recognition, reduction and removal, for misconceptions are to be effectively diagnosed and eliminated in the acquisition of accurate scientific knowledge. Explicitly presenting the misconceptions identified by these diagnostic tests to pre-service teachers, and students, may help scaffold and challenge teachers’ and students’ thinking and reasoning capacities and assist in the generation of multiple innovative practices needed to potentially overcome them (Angell et al. 2005). This will become part of a future research study in this regard. However, this development will clearly need to become supported by multiple modes and models of teacher development, such as, learning in expansive networks that incorporate school university partnerships, collaborative action research, reflective practices, to achieve lasting change in teachers' specialist knowledge base and pedagogic practices (Luft et al 2003; Penso et al 2001; Van Driel et al 2001).

Deliberative models of curriculum innovation, mentoring and support for teachers using a number of scaffolds and supports, such as, school-university partnerships, have been shown to build ethical trust and ownership of the change process (Mooney Simmie & Lang 2012; Young et al. 2015). In this study, we explored the use of diagnostic tests, lesson guides, effective teaching strategies and teacher education, to identify misconceptions in photosynthesis and to use them as a broad-based conceptual toolkit and as an entry point to a pedagogical cycle of recognition, reduction and removal at the level of the classroom.
8.4: What implications does conceptual change have on the design of curricula and instruction?

This study identified the need for broad-based conceptual toolkits for teachers, and teacher educators, for the diagnosis, reduction and eventual elimination of misconceptions, including such strategies as: direct observation, interviews, testing and questioning techniques, multiple written and textual approaches, such as, concept mapping and drawings (Akpinar 2007; Brown and Schwartz 2009; Kapyla et al 2009; Parker et al 2012; Partosa et al 2013), open-ended questions (Deshmukh 2012; Parker et al 2012 ), prediction-observation explanation (Domingos-Grilo et al 2012), multiple choice questioning (Balci et al 2006; Cakiroglu and Boone 2002; Krall et al 2009), two-tier diagnostic tests (Lim and Lee 2014; Svandova 2013), concept mapping (Ahopelto et al. 2011), drawings (Kose 2008), role play and models (Ross, Tronson, and Ritchie 2010), questionnaires (Boomer and Latham 2011), conceptual change texts (Mikkila-Erdmann 2001) and concept cartoons (Ekici, Ekici, and Aydin 2007). Science lessons which elicited debate and argumentation induced conceptual change through a guided process of cognitive dissonance (Erduran et al 2004; Pine et al 2001; Valanides 2000). Science needed to intrigue teachers and students and be taught in stimulating, imaginative and creative ways using multiple pedagogical strategies including dialogue and inquiry (Galvin et al 2015). While pedagogical strategies, used on their own or in combination, were found to generate cognitive dissonance for deep conceptual change none on their own was found to be sufficient to eliminate all misconceptions.

What teachers do in a classroom matters immensely, if teaching is indeed the most critical factor in student learning, then teacher preparation and continuing professional development stands to play a huge role in impacting student achievement (Marzano et al 2001). The review of the literature indicated the need for new and innovative efforts in
relation to the continuing education of all teachers (Abell 2008; Luera et al 2005; Sullivan-Watts et al 2013). In order to effectively diagnose deep rooted misconceptions, teachers needed inquiry oriented strategies and scaffolding and support for a change process (Zhao 2011). Increasingly studies showed that teachers needed access to broad-based partnerships in order to build effective capacity to interrogate, justify and change practices (Feiman-Nemser 2003). A best synthesis of CPD studies internationally has been conducted in New Zealand by Timperely et al (2007) who argue that it is not sufficient to merely give teachers a practical toolkit but that the teachers need to engage with the theory and with others, including teacher educators, to fully understand and make meaning in this regard. Overall the findings from this study suggest that we need to consider a new and different construct of science teacher education and CPD, a ‘good enough’ model of teacher education as a continuum, which positions teaching as a complex activity requiring the research base of a clinical practice and the thinking capacities of a dynamic activity taking place within an ever changing social, moral and political context, and the multilayered developmental supports to assist teachers and teacher educators enact this successfully (Ruohotie-Lyhty and Moate 2014; Opfer and Pedder 2011).

Almost 95% of the cohort felt that it was imperative that the voluntary additional pedagogy module making them aware of misconceptions be incorporated into their initial teacher education for a full semester. It is an important aspect to include in their pedagogy module as prior to the additional module pre-service teachers weren’t made aware of misconceptions, how they can effect students learning, the strategies they can use to identify and overcome them and where they can access relevant literature. The module also identified some of their own misconceptions which they would have taken and possibly embed in students they taught on their fourth year teaching practice. Students will
not accomplish meaningful learning unless the diagnosis of misconceptions are scaffolded and supported (Hattie 2012) so it is imperative that pre-service teachers are made aware of them in their pedagogy module (Johnston 2005; Russell and Watt 1990). The module was six weeks in length and showed positive results, a full semester with a focus on misconceptions and different methodologies to address the issue would undoubtedly be more beneficial to their teaching and learning. Students both nationally and internationally show great interest and passion for the subject Biology (Osborne et al 2003; OECD 2009; OECD 2012; Schreiner and Sjoberg 2005) compared to the other two Sciences; it is the teachers’ role to maintain this love and interest in the subject which can only be achieved if the same desire is felt by the teacher. Teachers are found to enjoy their teaching when they are provided with the necessary teacher education, resources, advice, guidance and support (Chang and Cheng 2008).

8.5: What challenges does school culture present for learning, teaching and continual professional development?

Nowadays teachers are often forced to teach towards the exam. This is mainly due to the extensive Biology syllabus and exam deadlines and the importance of STEM test scores for national policy imperatives and what has been aligned to national economic competitiveness. Schools and teachers are subject to a high degree of external control and influence and increasingly, international comparative testing regimes, such as, PISA, TIMSS and ROSE all signal an increasing politication of education (Giroux and MacLaren 1996). Curriculum content and modes of assessment are regulated externally. Both schools and teachers are the focus of public scrutiny, particularly in terms of measured attainment and because of ongoing concerns regarding quality and attainment (Smyth 1999). This area of public accountability has become deeply contested in the literature and divides between those who advocate that teaching is merely a technical
competence and can all be measured (Hattie 2012) and those who argue for broader aims from education and a more holistic view of science teacher education, especially among the philosophers on education, and a broader more intelligent type of accountability for teaching as an intellectual rather than a technically competent activity (Biesta & Miedema 2003, Biesta 2012). Teachers’ status are dependent on the grades they can produce in their class and students along with parents care more about the grade than understanding as it is the grade that provides them entry into college “points race”. Teachers are also aware that their professional competence is judged by the level of control they have over the students they teach (Denscombe 1985) which contributes to them holding back on active learning methodologies and practical work. Possibly in fear of losing control of the class or time being wasted in knowledge acquisition that some students will struggle with and which may not be finally assessed.

Interestingly when Irish teachers were interviewed by the Economic and Social Research Institute (Smyth et al 2006), they explained that they saw activity-based learning, practical work, encouraging questions and relating concepts to everyday life as important techniques for engaging students. However, when the students were asked about their classes such teaching approaches were not reported, further emphasising that yes teachers may be aware of the advantages of such strategies but may not want to implement such ways of teaching or are unable to do so. For the teachers with more experience there was also a strong emphasis on marking schemes and examination papers which is similar to the findings obtained by research funded by the NCCA (Symth et al 2006). Research from the cognitive Sciences has revealed that Science teachers and students learn in multiple ways, therefore it is essential that specific methodologies are used by teachers for both assessing misconceptions and guiding the development of more accurate scientific
knowledge (Hattie and Yates 2014). Teachers are relatively autonomous in their classrooms in terms of the pedagogical approaches they implement. However, they are subject to a range of internal as well as external control. The emphasis on quality assurance, as well as pressures caused by terminal state examinations, not only creates a stressful climate but also operates to curtail teachers’ willingness to use exploratory or innovative teaching methods (Hargreaves et al 1996). Furthermore, the multiple roles that teachers and schools are now expected to fulfil have become increasingly complex (Van Veen et al 2001).

For deep change to occur and to be sustained; a culture and ethos around identifying and tackling misconceptions in the teaching of biology to senior cycle secondary school students and their teachers needs to become embedded in the schools and teacher education programme in ITE in the Republic of Ireland (Dalin and Rolfe 1993). Teachers need to move away from transmission of knowledge to new forms of teaching that support knowledge acquisition (O’Grady et al 2013). It is inevitable that this older inherited cycle of teaching and teacher education and CPD needs to be broken, if one wants to break this cycle of teaching and teacher education, supports, scaffolds and resources must be provided to teachers (Halton 2004). As found in this research study providing teachers in Ireland with multiple opportunities to be creative and reflective in their teaching is crucial for their development. Unless schools and management provide for teachers’ continued growth through collaboration and teacher continuing education, the existence of optimal conditions for the educational development of students in the biology classroom cannot be assured.
Chapter 9: Conclusion

9.1: Introduction

This final chapter summarises the main conclusions drawn from this research study. The author discusses the research contributions this study has made to Science Teacher Education. Recommendations are suggested based on the findings from the study and ideas for future research work, and some new research questions, are proposed.

9.2: Significant Overall Findings and Conclusions

The findings from this study indicated that science teacher education programs need a multiplicity of pedagogical strategies to continually interrupt the cycle of misconceptions and to support all teachers and teacher educators increase the probability of conceptual change and the effective diagnosis, reduction and elimination of misconceptions (Asay and Orgill 2010; Galvin et al. 2015). It has been well documented that conceptual change requires reconceptualisations of an individual’s prior beliefs and not a simple technical replacement of the inaccurate concept with the accurate scientific concept (Treagust and Duit 2009). Conceptual change is a slow, demanding and gradual process. Overall the findings indicate that misconceptions in biology were widespread among senior cycle students and student teachers, and experienced teachers alike in the Republic of Ireland (Ahopelto et al 2011; Svandova 2013). From this study it is evident that pre-service and service Biology teachers in teacher education in Ireland need to develop their content knowledge and pedagogical strategies to diagnose their own misconceptions and assure capacity in recognising and restructuring their students’ misconceptions (Domingos-Grilo et al 2012; Johnston 2005).

The study identified broad-based conceptual toolkits for teachers, and teacher educators, for the diagnosis, reduction and eventual removal of misconceptions. This study has
indicated the need for new and innovative efforts in relation to the continuing education of all teachers (Abell 2008; Luera et al 2005; Sullivan-Watts et al 2013). This study and the studies reviewed emphasised the importance of the teachers’ role in providing opportunities for students to interrogate their misconceptions and engage in a proactive process of cognitive dissonance in this regard (Ravanis and Bagakis 1998). Implementing a new pedagogy of teacher education has its challenges (Vescio et al 2008). Teachers will need continual tutoring supports and conceptual toolkits and opportunities to engage with theory and expansive learning and partnership approaches to develop deep conceptual understanding in their classroom settings (Boomer and Latham 2011; Johnston 2005; Sullivan-Watts et al 2013).

9.3: Contributions of the Study to Science Teacher Education Research

This study was the first study that investigated misconceptions in Biology amongst students and teachers in Ireland. It has highlighted that similar to the international studies on misconceptions, Irish students and teachers hold a number of misconceptions in different Biology topics. Further investigation of this issue suggests that is due to teachers holding their own misconceptions, inaccurate text and representations in textbooks, lack of a specialist knowledge base in diagnosing the existence of misconceptions and the didactic style of teaching to a test that mostly examines lower order knowledge and that has traditionally reported in the Irish research literature.

Through highlighting these issues the author has opened up further areas for exploration. The results from phase three indicate that it is possible to make improvements in the conceptual understanding of students’, when the teacher is scaffolded and supported by a form of CPD on misconceptions that not only provides teachers with the necessary lesson guides and resources but also challenges their thinking and provides them multiple
opportunities to engage in argumentation and debate in relation to these issues. The research findings from this study are relevant to those involved in science teacher education for pre-service and service teachers. The research is also relevant to teacher CPD generally, at both national and international levels.

This research is valuable to those involved in initial teacher education programmes in Science and Biology and to the Irish Science Teachers Association and Professional Development of Secondary Teachers as it could inform how students need to be taught; and how teachers, both pre-service and service teachers, need to be educated and professionally developed. It creates an awareness of the need for specific CPD for both newly qualified and experienced teachers that is broad-based, that is technically competent and that seeks to go beyond the technical to assure a holistic perspective of education and to enact a ‘good enough’ model of teacher education (Galvin et al 2015). It could also provide teachers, teacher educators and policy leaders with some new thinking and ideas for future workshops and Continual Professional Development courses in the multiple teaching strategies explored during phase three for an inclusive classroom.

The research has further added to the literature available on teachers fear of change, school culture and the pressures placed upon them to get the syllabus ‘covered’ on time for the examination. This study has provided an insight into the practices of Biology teachers in Ireland and how with the correct resources, education and support they can enhance their students’ learning and their own teaching which contributes significantly to the field of curriculum innovation and development internationally.

The research has been presented at both national and international conferences at different stages of the investigation; allowing other academics access to the findings and providing
an opportunity for the author to collaborate with colleagues of the same interest and within
the field of science teacher education (Galvin 2014, 2015) (see Appendix 31 and 32).

9.4: Recommendations arising from the Study

The following recommendations are suggested by the author on completion of this research study:

A similar approach to Phase three of the intervention programme, largely focused on good instruction through using lesson guides and resources to teach Photosynthesis, could be taken by teachers when teaching difficult abstract concepts at junior cycle in lower secondary education in order to identify misconceptions at this stage and help to prevent their progression to senior cycle, to improve understanding of the important topics.

Students’ previous knowledge of different biological topics needs to be taken into account at all levels of the Irish education system. Teachers must not assume that students’ are ‘blank slates’ and have none of their own pre-conceived ideas. Results from this study have shown that in order to advance students’ conceptual understanding of a topic their misconceptions need to be challenged and changed. It is essential that all science teachers are scaffolded and supported in using an experimental and intelligent approach to their teaching, using multiple different teaching strategies, and that teachers know how to evaluate their effectiveness in seeking to develop students’ understanding and thinking capacities. In addition the resource of structured time needs to be given for students to restructure their conceptual understanding, as it is well documented that the restructuring of concepts is a slow and gradual process.
It is necessary at all levels of education, that misconceptions in Biology associated with different topics, are noted and addressed openly in class in order to challenge and deal with ideas that may be preventing true understanding of many Biology topics. For example, misconceptions once noted might be recorded and made available for teachers to access them when introducing a new topic to their students so they are aware of possible misconceptions their students’ may possess.

This study shows that pre-service Science teachers are not properly supported to diagnose, reduce and ultimately to remove their students’ misconceptions in biology, due to poor content knowledge, possessing misconceptions of their own and not being made aware of the resources, teaching strategies and literature available that could help overcome this problem. Pre-service teachers would benefit greatly if Third level institutions involved in Science teacher education provided more appropriate supports and scaffolding and preparation in this regard to enable them to deal with the demands of advancing students’ understanding of teaching accurate scientific knowledge.

This study suggests that new and different broad-based modes and models of CPD opportunities for Biology and Science teachers with PDST and University partnerships are desirable. These CPD partnerships could focus on providing teachers with updates on relevant subject matter knowledge, effective pedagogical content knowledge, structured time to collaborate and engage in argumentation and debate and demonstrate such pedagogy in order to successfully developing their own and their students’ conceptual understanding and tackling any misconceptions they may have held. These CPD opportunities should be sustained to allow teachers to change and develop new teaching approaches for the acquisition of accurate scientific knowledge accordingly. For this to be
successful, the CPD should take place over a significant period of time which would hopefully lead to a sustainable community of shared experiences and practices.

The approach taken in this the intervention programme in this research study can be applied to all junior and senior cycle Science programmes. Reforms of these programmes may over time lose the intense focus on factual knowledge and different ways may be found for assessing higher order conceptual thinking. Prolonged exposure to a broad-based conceptual toolkit for science teacher education, of partnerships, such as, school university partnerships, teaching resources and teaching for activity learning will undoubtedly go a long way in overcoming difficulties student teachers and service teachers have with misconceptions in the teaching of biological topics.

The diagnosis and reduction in misconceptions and increased conceptual understanding in this short intervention suggests that using the inquiry and broad-based approach from this study for an entire Biology course would have an immediate impact.

**9.5: Possible Directions for Future Work**

On completion of this doctorate the author acknowledged that findings from this research investigation could be further explored and developed. As a result a number of suggestions for further study are provided:

Teacher educators and researchers in Third level institutions in Initial Teacher Education (ITE) in Ireland and internationally play a leading role in identifying and addressing misconceptions that pre-service teachers possess. In this regard it appears that schools of science teacher education in third level institutions are in a unique place to offer a new centre for excellence and a broad-based conceptual toolkit in this regard in Ireland.
It is crucial that continual professional development is provided and attended by pre-service and qualified teachers to provide them with the necessary specialist knowledge base and to advance new spaces for innovative and inquiry-oriented teaching in biology as a ‘good enough’ model of practice for thinking, experimental work in the classroom, rather than rigidly defined and prescriptive lesson plans, and for teachers’ effective self-diagnosis of misconceptions in the teaching of biology within a sustainable community of practice.

A larger scale investigation on the effects of the conceptual change lesson guides intervention needs to be carried out in order to strengthen results that indicate that it has a positive effect on identifying and overcoming students’ misconceptions and statistically advancing their conceptual understanding of the topic.

In addition to Photosynthesis other topics that emerged in the literature reviewed and in phase one of the identification instrument as being problematic amongst students should also be addressed in a similar manner to those in the third phase using comparable strategies to what the author used (lesson guides, worksheets, models, video clips, concept maps, analogies).

9.5: Possible New Research Questions

- How much of an impact do the demands of the Economy, and particularly the globalised economy, have on biology curriculum development in Ireland?
- How prepared are pre-service science teachers in ITE, and biology pre-service teachers in particular, to take on this new role in the diagnosis and elimination of misconceptions into the future?
• How prepared are service science teachers in teacher education in Ireland, and biology service teachers in particular, to take on this new role in the diagnosis and elimination of misconceptions into the future?
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