NCCA

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National Council for Curriculum and Assessment

Background Paper and Brief for the Review of Junior Cycle Science

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1. Introduction

Science will be introduced in 2015 as a phase two subject as part of the new junior cycle. It is the first of the Science, Technology, Engineering and Mathematics (STEM) subjects to be phased in. The curriculum and assessment specification for Science will be published a year earlier, in September 2014. This paper provides a background for the development of a specification for Junior Cycle Science. It presents a brief sketch of the evolution of science as a school subject and the developments that were influential in shaping it, leading to the development of the 1989 syllabus and the 2003 revised Junior Certificate Science Syllabus in Ireland. The paper explores the response to the 2003 syllabus and the perceived divergence that has emerged between the intended curriculum and the enacted curriculum, before moving on to review the performance of Irish students in PISA assessments of scientific literacy. The purposes of science education for the 21st century are discussed, before a perspective on assessment is offered. The paper then focuses on current research and developments in science education and developments in the curriculum and assessment specifications for science in other countries, before finally setting out a proposed brief for the development of the specification. Appendix 1 offers a breakdown of the science curricula from other countries; this provides a broad lens through which to view the development of the new Junior Cycle Science curriculum and assessment specification.

2. The evolution and revolutions of Science as a school subject

Historically, science was introduced to second level education to simplify the transition from upper secondary school to university science and technology based studies. This is an important but limited purpose for science education. Nonetheless, as a school subject science have evolved over the last 100 years

> *……its original purpose has tended to remain the predominant determinant of the content and means of teaching and learning.*(UNESC0, 2008, p15).

Throughout the 20th century the aims of science education in school were malleable and there were many changes to science curricula during this time. Sometimes these changes constituted normal curriculum change as the science content is constantly undergoing refinement as science itself evolves (Orpwood, 2001). However, the latter half of the 20th century has seen at least two *curriculum revolutions*; these were changes that focused less on the content of the science curriculum and more on the purposes for learning science (Orpwood, 2001; Atkin et al 1996).

World War II focused the attention of many countries on the need for military preparedness; hence, scientific research became a key element of national security. In the aftermath of the surprise success of the launch of the Russian Sputnik, the US government invested heavily in new science curriculum. The aim of this investment was to generate more and better scientists to compete in the Space Race with Russia, reinforcing the role of scientific research in supporting national security imperatives. This not only marked the beginning of the Cold War but also the first of the *curriculum revolutions* of the 20th century.

Over time, the attention to science never waned but the *reasons for anxiety about the quality of science education expanded* (Atkin & Black, 2003, xi). It was acknowledged that quality science education had the potential to improve the economy, protect the environment, and improve students' preparation for employment as well as preparing students to become scientifically informed citizens. This spurred the second *curriculum revolution* in the 1980s, which was the integration of Science Technology and Society (STS). The integration of STS reflected the continuing concern about student engagement with science (ASE, 2006). Once again the changes focused less on the scientific content and more on the complex relationships between science, technology, society and the environment (Orpwood, 2001).

Despite these changes, there was some evidence that the changes in teaching and learning envisioned by curriculum developers failed to take root in the classroom (Osborne and Dillon 1998). The most common reason cited for this was that the assessment change did not align sufficiently with curriculum change (Orpwood, 2001). This is something that is explored in more detail in section 6 of this paper.

The learning experiences' of students is strongly influenced by the approach to science education adopted by their teacher. Changes to curriculum and assessment often seek to promote a particular approach. The report *Science Education Now* (European Commission, 2007, p. 9) points to the existence of two historically contrasted approaches in science education: the *deductive* and the *inductive* approach. The deductive approach is the more traditional approach, while the inductive approach is oriented towards observation and experimentation. By the end of the 20th century, the inductive approach had grown in prominence and became known as inquiry-based learning (IBL).

Inquiry-based learning is based on the investigation of questions, scenarios or problems. Inquirers identify and research issues and questions to develop their knowledge or solutions. To facilitate inquiry-based learning, the focus in science education has moved away from knowledge of a wide range of facts and theories, towards core scientific ideas that enable students to understand science and recognise its relevance to events and phenomena in their own lives. In this way, the fundamental facts, concepts and theories of science are anchored to unfolding themes. (Harlen, 2010).

There are many initiatives in place that promote inquiry-based learning in Junior Certificate Science. STEPS is an Engineers Ireland programme which encourages primary and post-primary students to explore the world of science, technology, engineering and mathematics while also promoting engineering as career choice. Discover Sensors, a programme which is managed by Science Foundation Ireland, has worked closely with 120 teachers in 35 schools trialling practical inquiry-based science teaching and learning tools and techniques incorporating assessment for learning. Centres such as The National Centre for Excellence in Mathematics, Science Teaching and Learning (NCE-MSTL) at the University of Limerick, the Eureka Centre at University College Cork (UCC) and the Centre for the Advancement of Science and Mathematics Teaching & Learning (CASTeL) at Dublin City University among others are examples of third level institutions that work closely with teachers and students to research good practice in science education and provide professional development.

Scientific inquiry is popular with students, evidenced by the growing popularity of events such as BT Young Scientist and SciFest. Both science festivals encourage active, collaborative, inquiry-based learning and are Irish initiatives. Participation in the Young Scientist and Technology Exhibition has grown from 230 students in 1963, to 3,842 in 2012. Participation in SciFest has grown from 1612 students from 100 post-primary schools in 2008, to 3491 students from 240 schools in 2013.

It is worth noting that many of the initiatives in Ireland that are in place to promote science receive both public and private funding. This is very positive and welcome but not surprising as the promotion of innovative science, engineering and technology are viewed as being fundamental to Ireland's future economic prosperity.

The Junior Certificate Science Syllabus 1989

Science (with Local Studies) and Science (without Local Studies) were introduced in 1989 as one of the first group of new Junior Certificate syllabuses. They were examined for the first time in 1992. The 1989 Junior Certificate Science syllabuses adopted a core and extensions model to accommodate the scope of the former Intermediate Certificate and Day Vocational Certificate Science courses. Each syllabus was presented as a list of content, which was intended to be taught and learned with an emphasis on students' experience of science as a practical activity (DES, 1989). However, there was no explicit indication of the desired learning outcomes associated with the content (NCCA, 2006). Ninety-nine percent of students following the 1989 syllabuses opted for the Science (without Local Studies) option. These students were assessed by means of a terminal written examination only. In the case of the small number who opted for Science (with Local Studies) the assessment consisted of a terminal written examination and a second externally assessed component where the student presented an investigative project. In the terminal written examinations of both 1989 science syllabuses, the examination papers were divided into sections and each section incorporated a very significant level of question choice (SEC, 2006).

The 1989 Junior Certificate Science Syllabus was revised in 2003. The syllabus revision was prompted by a noticeable declining interest in science, particularly the physical sciences in senior cycle (DES, 2002). The structure of the 1989 syllabus and the degree of choice involved in its assessment facilitated the omission of some aspects of science, particularly physics and chemistry. This was identified as contributing to a fall-off in the uptake of physics and chemistry at senior cycle, with a follow-on impact at third level. Furthermore, the approach to science at junior cycle needed to be aligned with the approach that had been recently introduced in the revised primary curriculum. Appendix 2 offers a brief summary of the 1999 Primary Science Curriculum.

The revised Junior Certificate Science Syllabus 2003

The 2003 syllabus was introduced in schools in September 2003. It was examined for the first time in June 2006. Although much of the content of the 1989 syllabus was retained, it differed from its predecessor in three significant ways. Firstly, a simplified structure was adopted in the 2003 syllabus and all students were required to study each of the three major areas of science: biology, chemistry and physics. This was designed to encourage uptake of physics and chemistry in senior cycle. Secondly, there was an increased emphasis on an investigative approach to science. Thirdly, the science topics were accompanied by a set of learning outcomes which described what students should be able to do rather than what they should know.

One of the main reasons for revising the syllabus was to effect a *movement towards doing rather than simply observing and learning off science* (NCCA, 2006, p3). This fresh approach was reflected in the introduction of a second assessment component, for which students could obtain up to 35% of the overall marks: 10% for the completion of 30 specified practical activities (Coursework A) and 25% from the external marking of reports on two investigations prescribed by the State Examinations Commission (chosen from a list of three investigations) or a report on one larger investigation of the student's own choice (Coursework B). The mandatory practical activities in Coursework A are divided evenly between the three core areas of science. The terminal examination paper, which accounts for the remaining 65% of the marks, consists of three equally-weighted sections, biology, chemistry and physics, all of which the student must answer.

Responses to the 2003 Syllabus

As much of the content from the previous syllabus was retained, many teachers felt that volume of content in the 2003 syllabus leaves little time to engage in inquiry-based learning or use an investigative approach in the mandatory practical activities (Cheevers, Eivers & Sheils 2006). Overloading of content is not unique to Ireland, and was one of the major drivers for the recent reform of science education in the USA, where the framework for K-12 science education includes the following commentary:

> *Not only is such an approach alienating to young people, but it can also leave them with just fragments of knowledge and little sense of the creative achievements of science, its inherent logic and consistency and its universality. Moreover, that approach neglects the need of the student to develop an understanding of the practices of science and engineering, which is as important to understanding science as knowledge of its content*. (NRC, 2012, p10)

Nonetheless, the 2003 syllabus was seen as a positive development in science education in Ireland in its aim to promote an inquiry-based approach to teaching and learning and move the focus away from the terminal examination by including a second assessment component. A composite report on science by the DES Inspectorate (2008) reported many positive findings on the teaching and learning of science, notably that *Science was made relevant to students and linked to everyday experiences in many lessons*… *Practical laboratory activities were effectively organised in most schools* (DES, 2008, p47). However, one worrying finding was that: *In some schools, students were not learning about Science in an investigative way, as required by the syllabus* (DES, 2008, p37). This raised concerns about whether a gap was emerging between the intended curriculum and the enacted curriculum, one that could be explained in part by the previously mentioned overemphasis on content in the syllabus.

A research study prepared for the DES by the Education Research Centre to examine the teaching of Junior Certificate Science from a teacher's perspective reported that 88% of respondents said that they were happy with the content of the 2003 syllabus. However, almost one-fifth included a written comment criticising the content, style or lack of clarity in the learning outcomes. Although views were sometimes contradictory, common complaints related to lack of clarity on the depth with which topics needed to be covered and an overemphasis on learning facts, with no time to examine concepts (Cheevers, Eivers & Shiel. 2006). Nonetheless, the curriculum has been transacted in the classroom with varying degrees of success. This is reflected in the conclusions of the ERC report:

> *The revised Junior Certificate Science syllabus was intended to differ from its predecessor in a number of ways……..Teacher responses suggest success in achieving at least some of these aims. They report greater use of investigative approaches by both themselves and their students, and improved student ability to apply scientific processes.* (Cheevers, Eivers & Shiel. 2006, p27).

Assessment of the 2003 Syllabus

In a report on assessment of the 2003 syllabus, Cheevers et al (2006) reported that many of the teachers they interviewed were dissatisfied with the assessment of coursework. Some teachers complained that there were too many mandatory activities in coursework A. Too much time had to be spent writing up experiments, with little attention to how well students actually carried out the experiments. Other teachers expressed the view that conducting and writing up the mandatory activities consumed all of the class time allocated to practical work, leaving no time for discussion and analysis. Some of these points may raise issues of pedagogy as much as issues related to the number of mandatory activities. 40% of teachers were not satisfied with Coursework B; one in ten teachers indicated that they were very dissatisfied with this element of the syllabus. This is a worrying statistic as the introduction of Coursework B as an element of assessment was intended to reduce the focus on the terminal examination and to encourage an inquiry-based learning approach to Junior Certificate Science.

There is little doubt that the 2003 syllabus has encouraged many positive changes; 87% of teachers surveyed in 2006 felt that the 2003 syllabus had led to an increase in their use of an investigative approach to teaching science, while 41% noted an increase in their own use of ICT in lessons. Most, however, reported *no change in the emphasis they placed on preparing students for the written Junior Certificate examination* (Cheevers, Eivers & Shiel, 2006, p17). This focus on the terminal examination could be viewed as inhibiting genuine engagement with the spirit of the 2003 syllabus. Over time, it has also led to a degree of inertia in learning, teaching and assessment practice which the development and introduction of a new specification will need to address.

The Chief Examiner's Report for 2010 reveals some further issues. It reported that the *presentation of similar coursework by a number of candidates is a cause of some concern* (SEC, 2010, p28). It also noted that the number of candidates who presented an investigation of their own choice was very small, at 0.6%, and some of the self-nominated investigations presented for examination were

> *…investigations previously set by the SEC in the guise of candidate's own investigation and an apparent use of the published marking scheme as a guide to carrying out and presenting the investigation (ibid, 2010, p15).*

Section summary
Through the 20th century science education has adapted to meet society's needs. How science and scientists work is seen as an important component of science education. Across the world, curricula have reduced the breadth of their content and focused on the development of core scientific ideas, showing clear indication of progression in the depth of student understanding of scientific processes and ideas over time. In Ireland, post-primary science curricula have been revised to respond to changing needs of learners. The most notable change introduced with the 2003 syllabus was the inclusion of a practical assessment component which was intended to reduce the focus on the terminal examination and to encourage an inquiry-based learning approach to Junior Certificate Science.

3. PISA assessment of scientific literacy

The Programme for International Student Assessment (PISA) is a project of the Organisation for Economic Co-operation and Development (OECD), designed to assess the scientific, mathematical, and reading literacy skills of 15-year-olds. It takes place in three-yearly cycles, the first of which was 2000. In each cycle, one of the knowledge domains is designated as the main focus of the assessment. Scientific literacy was the focus for the first time in PISA 2006, but test data were also gathered on reading and mathematical literacy. Students in 57 countries (including all 30 OECD countries) took part in the assessment, which was implemented in Ireland in March/April 2006. Science was a minor domain in 2009 and 2012. The results of PISA 2012 will be published in December 2013.

PISA 2006

PISA 2006 assessed students' ability to perform scientific tasks in a variety of situations. These tasks measured students' performance in relation to their science competencies and their scientific knowledge. PISA assessed three broad science competencies: identifying scientific issues, explaining phenomena scientifically and using scientific evidence. The PISA tasks required scientific knowledge of two kinds: knowledge of science and knowledge about science.

Items assessing knowledge about science were divided into ones that examined scientific inquiry (how scientists acquire knowledge – how they get their data) and scientific explanations (the results of scientific inquiry – how the data are used). The PISA 2006 science assessment also evaluated students' attitudes in three areas: interest in science, support for scientific inquiry and responsibility towards resources and environments.

Ireland's mean score in science was 508, which is higher than the OECD average of 500.8. The mean score for Ireland is the 20th highest of the 57 participating countries, and the 14th highest of the 30 OECD countries. In comparison, Ireland's mean score in reading literacy was 6th highest of the 56 participating countries, and 5th highest of the 29 OECD countries.

PISA 2009

In 2009, scientific literacy was a minor domain of assessment and there was no change in the average mean score of Irish students in this area, still above the OECD average. There were 11 countries whose scores were significantly higher in 2009 compared to 2006. Nonetheless, Ireland's 2009 rank among OECD countries remained the same at 14th out of 34, and climbed two places from 20th to 18th among the 57 countries that participated in both the 2006 and 2009 cycles. In terms of proficiency levels, the proportion of Irish students scoring at/below Level 1 or at/above Level 5 in scientific literacy did not change significantly between PISA 2006 and PISA 2009. However, on average across OECD countries, the percentages of these students dropped significantly.

Emerging trends

The fact that Ireland's science ranking in 2006 is similar to that in 2000 and 2003 and remained unchanged in 2009 suggests that the 2003 syllabus has not yet led to any discernible improvement in students' science achievement. Since the 2003 syllabus is closer than its predecessor to the PISA view of science, and the PISA definition of scientific literacy is included in the rationale for revising the syllabus in 2003 (DES, 2003), it is disappointing that performance on PISA has not improved.

In 2000, 43% of science items were considered to deal with topics that were not included in the syllabus, while close to half were judged to be based on concepts unfamiliar to students following the 1989 syllabus (Shiel et al, 2001). In the 2006 science assessment, only 16% of items of items were not directly related to 2003 syllabus material, and only 4% were based on concepts that were unfamiliar to students. In light of these findings, it is rather surprising that there was no evidence of improvement in student performance in Ireland.

An absence of a significant improvement in the performance of Irish students in international comparative studies assessing scientific literacy is not limited to PISA. In 2011, primary school pupils in Ireland participated in *Trends in International Mathematics and Science Studies (TIMSS)* for the first time since it was originally conducted in 1995. In both the 1995 and 2011 TIMSS studies, Ireland scored significantly above the TIMSS science study centre point. However, it is worth noting that, despite intensive primary curriculum reform, achievement by Irish primary pupils in science is broadly similar to the Irish performance on TIMSS in 1995.

Section summary

In PISA 2006 Ireland was marginally above the OECD average in science achievement. Ireland's mean score did not change in 2009.

Ireland's performance in PISA by ranking, scores and score relative to the OECD average shows that Ireland has not shown any discernible improvement in students' science achievement since previous PISA science assessments in 2000 and 2003.

4. Life-long learning in science

Much of children's early learning and development takes place through play and hands-on experiences. The four themes of Aistear; the Early Childhood Curriculum Framework: well-being, identity and belonging, communicating, and exploring and thinking provide a foundation for the development of scientific thinking and practice. As they explore their world through play, children develop and use skills and strategies for observing, questioning, inquiring and problem solving.

In the primary curriculum, the themes of Aistear are further developed as priorities that reflect five fundamental areas for children's development. The priorities focus on helping children to develop life skills; be good communicators; be well; engage in learning; and develop a strong sense of identity and belonging. These priorities provide the foundation for further development in the junior cycle key skills of managing information and thinking, being creative, communicating, staying well and managing myself. These skills are then further developed during senior cycle.

Table 1. Early childhood themes, primary priorities, junior cycle key skills and senior cycle key skills

Early childhood themes	Primary priorities	Junior cycle key skills	Senior cycle key skills
Exploring and thinking	Develop learning, thinking and life skills	Managing information and thinking	Information processing
Communicating	Communicate well	Communicating	Communicating
Well being	Be well	Staying well	Being personally effective
Identity and belonging	Have a strong sense of identity and belonging	Working with others	Working with others
	Engage in learning	Managing myself	
		Being creative	Critical and creative thinking

Students start to learn about science in early childhood. Their curiosity about what they see around them and their initial conceptions about how the world works continue to develop as they progress through school, guided toward a more scientifically based and coherent view of the world around them. Along their science journey, students come to appreciate how scientists work and the discipline of scientific practice.

Science learning extends from early childhood to long after they have left school. Students will continue to learn about core scientific ideas over their entire lives. Because of this, it is important to consider how science content is presented so that students can build on their prior understanding, and progression in learning is visible. It is also important to link students' science activities to the world around them to improve student engagement with science and to prepare them for their lifelong journey of science learning.

Bridging between primary and post-primary science

Although there are differences between the areas of learning in the Primary Science Curriculum and the 2003 syllabus as outlined earlier, closer inspection reveals that there are many similarities in the aims, content and skills.

It was noted in the *Science in Primary Schools, Phase 2* report:

> *In comparing the science curricula at primary level and Junior Cycle, it would appear that there are many commonalities of experience envisaged for students within the two school settings, whilst a development or progression of experiences would also be inherent in the documents. The Primary Science Curriculum therefore presents an opportunity to prepare pupils for their future study of science at post-primary level, and, conversely, the Junior Cycle Science Syllabus allows teachers to build on students' earlier experiences at primary school*.
> (Murphy, Varley & Veale, 2008, p45).

The extent to which curriculum continuity has been recognised by both primary and post-primary teachers is less clear. A session introducing the primary school science curriculum was included as part of the initial in-service training for teachers on the 2003 syllabus.

However, in a report that post-dates the in-service training, it was noted that *most teachers (all teaching junior cycle students) described themselves as unfamiliar with the science content and processes in primary school science* (Cheevers et al, 2006, p27). Although a considerable amount has been achieved in engaging primary school pupils with science since the introduction of the Primary Science Curriculum in 2003, some issues were highlighted in *Science in Primary Schools, Phase1* report (Murphy, Varley & Veale, 2008). The report raised concerns about the confidence of some teachers to teach Science. This may have contributed to the kind of finding reported in *Science in Primary Schools, Phase2*:

> *Many of the students in the case study did not appear to have had frequent experiences of engaging with the Primary Science Curriculum. (Murphy et al, 2008, p147)*

Nonetheless, the *same* report found that these case study students had a positive perception of post-primary school science following their pre-transfer school visits to post-primary school and

> *...it would appear that for virtually all of these students, their subsequent experiences of science in post-primary school met or exceeded their expectations (Ibid, p147).*

The question of primary teachers' lack of confidence to teach science was put into context in the recent ERC report *National Schools, international contexts: Beyond the PIRLS and TIMSS test results.* This report used the data arising from Ireland's participation in PIRLS and TIMSS 2011 to examine several areas of interest. Chapter 5, on *Teachers and Teaching Practices,* reported that

> *…the percentage of pupils in Ireland whose teachers were very confident teaching science was about two-thirds of the corresponding TIMSS average. Specific areas where confidence was particularly low in science teaching included answering pupils' questions about the subject, and providing suitably challenging tasks for high-performing pupils. Irish teachers' lack of confidence in these areas may be considered in light of their relatively low participation in subject-specific CPD. (Clerkin & Eivers, 2013, p101)*

In *A Consultation with young people on the reform of the Junior Cycle* (DCYA, 2011) it was revealed that although Science was one of the subjects students most enjoyed studying in primary school, it was not one of the subjects they would be most likely to continue in senior cycle. In the 2007 *Relevance of Science Education in Ireland* (ROSE) report, some of the lowest ratings given by Irish students were for topics that form major parts of the 2003 syllabus (e.g. atoms and molecules, how plants grow and reproduce and electricity). It was also reported that although a large percentage of Irish students were optimistic about the ability of science and technology to find solutions to environmental problems and disease, and were strongly of the opinions that care for the environment was their personal responsibility; the majority of them do not want to become scientists (Matthews, 2007). Many students do not see the relevance of the science that they learn in school to their everyday lives. They lack awareness of the links between science and their world. If students develop their understanding by collecting and using evidence to explore core scientific ideas, this may have a positive influence on their attitudes to science as well as their understanding.

It is clear that a significant effort has been made by teachers, the DES and curriculum developers to progress the science education at both primary and lower secondary level in Ireland. The development of this specification for JC Science presents an opportunity to consolidate and advance these efforts and to focus on a smoother transition between primary and post-primary Science.

Progression to senior cycle

A specification for Junior Cycle Science that focuses on skills development and problem solving provides a solid foundation for progression to senior cycle science. The five senior cycle key skills of critical and creative thinking, being personally effective, communicating, working with others and information processing are central to the revised Leaving Certificate Chemistry, Biology and Physics specifications that are currently being revised, and to Agricultural Science, when it is revised. In senior cycle, students will further develop their critical thinking and problem solving skills as they explore the fundamental concepts and theories of science. They will use their inquiry skills to consider the validity and reliability of data and to justify conclusions. They will use their understanding of the ideas which underpin the collection, analysis and interpretation of data to appreciate the limitations of scientific evidence.

Section summary

Science learning is a continuum that starts in early childhood and continues throughout a person's life. It starts with a child's curiosity about what they see around them, and is guided toward a more scientifically-based view of the world as they progress through school. It extends outside school and after school as they learn from their everyday experiences of life and their engagement with science-related material in the media. Hence, the importance of engaging a young person's curiosity, their sense of fascination and wonder of science and their understanding of how science works cannot be overstated.

It is important to consider how science content is presented so that students can build on their prior understanding, to ensure progression in learning is visible and to link students' science activities to the world around them.

Progression in science education between primary school and post-primary school is essential. However, the extent to which curriculum continuity is recognised between primary and post-primary teachers varies.

A specification for Junior Cycle Science that focuses on skills development and problem solving provides a solid foundation for progression to senior cycle science. In senior cycle, students will further develop their critical thinking and problem solving skills as they explore the fundamental concepts and theories of science.

5. Purpose of science education in the 21st century

Humanity's fascination with how the world works has driven scientific endeavours for centuries. More recent motivations for scientific explorations are rooted in the need to find solutions to challenges that face humanity. Many of these challenges –energy demands, providing sufficient food and water, climate change and disease control– will require major contributions from the scientific community. These challenges will require not only innovative science solutions, but also social, political and economic ones that are informed by knowledge of the science that underpins the challenges (NRC, 2012). The scientists of the future, capable of such innovation will require the support of scientifically literate social, political and economic decision makers. At a local level, individuals have to make decisions that affect their own health, energy consumption, food and water supply and their immediate environment (PISA, 2012). The solutions to these problems

> *…cannot be the subject of informed debate unless young people possess certain scientific awareness…this does not mean turning everyone into a scientific expert, but enabling them to fulfill an enlightened role in making choices which affect the environment and to understand in broad terms the social implications of debates between experts. (EC, 1995, p28)*

The Expert Group on Future Skills Needs (EGFSN) advises the Irish Government on current and future skills needs of the economy and on other labour market issues that impact on growth in enterprise activity and employment in Ireland. In their most recent report, *Monitoring Ireland's Skills Supply: Trends in Education and Training Outputs* the EGFSN has explicitly linked future economic prosperity to

> *...an education and training system that is focused on the needs of individuals, communities, employers and the economy. (*Burke, Condon & McNaboe., 2013*, p4).*

In these contexts science education is important for everyone, including those who do not pursue a career in science. Science education in the 21st century should meet the needs of those students who will become the next generation of scientists and those who will live and work in a world increasingly shaped by scientists.

Science as a subject is composed of three elements: a body of knowledge, practices of science and the nature of science. Over time, as we discussed in section two of this paper, the focus in science education has moved away from the acquisition of a wide range of science content to the development of a limited number of core scientific ideas which provide a context for students to continually build on and revise their scientific knowledge and skills as they progress in their learning. Limiting content to core scientific ideas allows space for what is often the least familiar element, the nature of science, to be included in a contemporary school science curriculum. Many interpretations of the phrase *nature of science* exist amongst science educators, science philosophers, science historians, and scientists (Abd-El-Khalick, Bell & Lederman, 1998; Clough, 2007; Lederman & Niess, 1997; Mathews, 1994; McComas et al., 1998). However, there is a common understanding that the phrase *nature of science* generally refers to the epistemology of science; it is a particular way of thinking that is underpinned by certain values and beliefs inherent to scientific knowledge or the development of scientific knowledge. This is the interpretation of the phrase used in this paper. McComas et al. (1998), put it succinctly when they said that *the nature of science describes how science functions.* Developing students' understanding of the nature of science has a practical and cultural value. It contributes to the student's lives outside the classroom and beyond school, as many of the ethical dilemmas that will confront students have a scientific basis.

Many international research studies have established the essential elements that constitute the *nature of science*. A Delphi study of the expert community (Osborne et al. 2002) brought together 23 experts drawn from the communities of leading and acknowledged science educators, scientists, science historians, philosophers and sociologists and expert science teachers. The outcome of the research was a set of nine themes about the *nature of science* that were considered to be an essential component of school science curricula. The themes emerging from this study were similar to an earlier study on the *nature of science* in international science education standards documents (McComas, W.F.& Olson, J.K. 1998).

Table 2 is a comparison of the themes emerging from the Delphi study with the most prevalent ideas (ideas found in six or more national curriculum documents) about the *nature of science* from McComas & Olson's (1998) study of national standards. These findings support the argument that more time should be devoted to teaching about science and less time to teaching details of the scientific content that has always been there; that the nature of science and its processes of inquiry should be placed at the core rather than at the margins of science education.

Table 2. A comparison of the themes emerging from Delphi study with the most prevalent ideas about the nature of science from McComas& Olson's (1998) study of national standards.

McComas and Olson	Delphi Study
Scientific knowledge is tentative	Science and certainty
Science relies on empirical evidence	Analysis and interpretation of data
Scientists require reliability and truthful reporting	Scientific method and critical testing
Science is an attempt to explain phenomena	Hypothesis and prediction
Scientists are creative	Creativity, science and questioning
Science is a part of social tradition	Cooperation and collaboration in the development of scientific knowledge
Science has played an important role in technology	Science and technology
Scientific ideas have been affected by their social and historical milieu	Historical development of scientific knowledge
Changes in science occur gradually	Diversity of scientific thinking
Science has global implications	
New knowledge must be reported	

Currently, the 2003 syllabus is dominated by the exact sciences of physics, chemistry and biology with significant elements of the *nature of science* missing. In the new science specification for junior cycle, embedding the key skills in learning outcomes, with due regard to international developments in science education, will produce a contemporary specification that will be relevant for students and develop their scientific literacy and their understanding of the physical and natural world.

The change from a curriculum based primarily on knowledge and content to one in which knowledge *of* and knowledge *about* science are interwoven with skills development will be a particular challenge in science, requiring development in teaching culture and styles of assessment. An analysis of similar curricular reforms in other countries indicates that such a shift will need to be supported by professional development around the teaching of critical thinking and problem-solving skills, and changes in classroom practice. The development of the practices of science and the understanding of the nature of science needs to permeate all science lessons. The rationale for conducting student investigations should focus on the development of specific scientific skills and practices rather than reaching a particular conclusion. Realistically, such changes may take some time to achieve and embed. But they will be most effectively achieved if there is a shared understanding by all the partners of the purposes of science, professional development on the scale needed and a strong foundation of peer support within the teaching profession.

Section summary
Science education in the 21st century should meet the needs of those students who will become the next generation of scientists and those who will live and work in a world increasingly shaped by scientists and their work. As well as knowledge of science, students will learn about the nature of science. A number of themes about the nature of science have emerged that should form essential elements of contemporary curricula. These themes should be at the core rather than at the margins of science education. Successful implementation depends on a shared understanding by all the partners of the purposes of science education, professional development on the scale needed and a strong foundation of peer support within the teaching profession.

6. Perspectives on assessment

The most recent purposes of science education are focused on the need to link science to the wider social context. Curriculum change, which occurs in this context, can be classified as a revolutionary change. The lesson to be learned from past curriculum revolutions outlined in section 2 is that changes in curriculum need to be closely aligned with changes in assessment. Osborne and Dillon (1998) argue that *for too long, assessment has received minimal attention (p9).* They also make the point that it is the responsibility not just of the teacher but also the assessment system to shape the pedagogy which enacts the curriculum (2008). Millar (2012) views assessment as *an invaluable tool for the future of science education* and shares the view of Osborne and Dillon that assessment needs to be given a higher priority.

The alignment of curriculum and assessment requires a close analysis of the purpose of assessment and of the forms of assessment. The Framework for Junior Cycle emphasises that the purpose of assessment is to support learning. The development of assessment to support learning rather than to summarise students' achievement brings assessment closer to the point of teaching and learning. The new assessment model will optimise the opportunity for students to become reflective active participants in their learning and for teachers to support this. This will also involve the assessment of a wider range of students' learning experiences and skills than currently is the case. It is an established fact that assessment is a key driver of pedagogy. It is also critical to take account of the student's perspective on assessment, assessment tasks that are seen as relevant to students' lives can increase student engagement. This can be achieved in a number of ways, for example, through the use of ICT for assessment.

Assessment and ICT

The key skills for junior cycle will be embedded in the learning outcomes in the subject specification. ICT is integrated into the elements and learning outcomes of each of the key skills; hence, the digital world will be an integral part of science in junior cycle. This should also be true of the assessment of science in junior cycle.

The concept of an e-portfolio is a useful idea to be considered in relation to Junior Cycle Science. It is envisaged that second year would be a suitable stage in Junior Cycle to develop portfolio content to be used as part of the school-based assessment component. This is not to say that students could not begin to use an e-portfolio from first year to develop their digital competencies. One advantage of an e-portfolio system is that it could provide greater visibility of learning, increasing the opportunities for formative feedback from the teacher and for self/peer assessment. This also facilitates the shift towards student-centred learning and allows schools to move forward from the students and not backwards from the assessment. Thus, assisting students to

> …*acquire not just a wide range of knowledge but new skills and competencies that make them adaptable problem solvers and self-motivated students, capable of facing unpredictable challenges throughout the life cycle* (Hirsch, 1999, p94).

Another advantage of an e-portfolio system is the greater variety of assessment items that can be used to record evidence of the learning outcomes achieved by the students to contribute to the assessment of the school-based component of Junior Cycle Science. Digital portfolios could allow for development of audio-visual recordings of investigations, graphs generated from data loggers could be presented as part of reports, voice-annotated presentations (VAPs), videoclips to illustrate an understanding of a scientific concept, to name just a few. An e-portfolio allows students to manage and present their stored work and showcase their learning of Science.

Section summary
Changes in curriculum need to be closely aligned with changes in assessment, therefore assessment needs to be given a high priority as it is the responsibility of not just the teacher but also the assessment system to shape the pedagogy which enacts the curriculum. The digital world will be an integral part of science in junior cycle; this should be true also with regard to assessment. The concept of an e-portfolio is a useful idea to be considered in developing the specification for Junior Cycle Science. It could provide greater visibility of learning and facilitate the shift towards student-centred learning and allow schools to move forward from the students and not backwards from the assessment.

7. Features of 21st century science specifications

Twenty-first century science curricula emphasise the development of an understanding of the *nature of science*. How they are structured to achieve this varies widely. The trend across Europe is that school science at lower secondary level is becoming more integrated, although the pace of change is relatively slow. In curricula used in Australia, New Zealand, Canada and the United States, science content is usually presented in themes which provide contexts for skills development. Appendix I outlines the science curricula in a number of places around the world.

Although the design and structure of the curriculum specifications described in Appendix 1 vary considerably, they share many similarities (Table 3).

Table 3: International comparison of a variety of science curricula.

Jurisdiction	Areas of learning focus on core scientific ideas	Content provides context for learning skills and process	Clearly defined progression
Wales	✔	✔	✔
Scotland	✔	✔	✔
Australia	✔	✔	✔
Ontario Canada	✔	✔	✔
N. Ireland	✔	✔	✔
USA[1]	✔	✔	✔
New Zealand	✔	✔	✔
Japan	✔	✔	

There are many similarities in how these curricula are divided into areas of learning under which the core ideas for science are organised. Table 4 gives a breakdown of these areas of learning and compares them to the breakdown of the Irish primary and post primary science

[1] Refers to the Next Generation Science Standards which were released in April 2013, see Appendix 1 for more details.

curricula. It also shows how the primary science curriculum, which did not evolve from a pre-existing form in Ireland, has a similar construction to curricula in other countries.

Table 4. Areas of learning in the junior cycle, primary and international lower secondary science curricula

Jurisdiction	Areas of Learning			
Ireland (P.Primary)	Physics	Chemistry	Biology	
Ireland (Primary)	Energy and Forces	Materials	Living things	Environmental awareness and care
Wales (KS3)	How things work	The sustainable earth	Interdependence of organisms	
Scotland	Forces, electrical and waves	Materials	Biological systems	Planet earth
Australia	Physical sciences	Chemical sciences	Biological sciences	Earth and Space
Ontario	Understanding matter and energy	Understanding structure and mechanisms	Understanding life systems	Understanding Earth and space systems
N Ireland (KS3)	Forces and Energy	Chemical material and behaviour	Organism and Health	Earth and Universe
New Zealand	Physical world	Material world	Living world	Planet earth and beyond
Japan	Matters and phenomena related to substances and energy	Living things and natural matters and phenomena		

Internationally, it is now usual to use knowledge of science facts and theories as a context for the development of skills and attitudes rather than as an end in itself. Assessment has a key role to play in supporting this approach to science education.

For example in the Welsh curriculum, science content provides the context for the development of the science process skills as outlined in table 5.

Table 5: Breakdown of the processes of science inquiry in *Science in the National Curriculum for Wales.*

Processes	Strands
Planning	Finding evidence, information and ideas
	Predicting
	Methods and strategies
	Fair testing
	Determining success criteria
Developing	Observing and measuring
	Monitoring progress
	Communicating findings
	Reviewing findings
	Explaining
	Conclusions and decisions
Reflecting	Reviewing success
	Evaluating learning
	Linking learning

Progression is indicated as a broad description of what is expected of students as they move through a period of learning rather than as a sequence of activities. The simpler ideas provide a basis for more complex ones, which help students to explain a wider range of ideas that enable understanding across a range of experiences.

Literacy and numeracy

The development of literacy and numeracy skills is a core element of science learning. The construction of an argument and its critical evaluation, and the interrogation of data are central to science and to the learning of science. Language literacy strategies provide the tools necessary to read scientific material. The following illustrates how Luke and Freebody's (1999) four resources model of literacy applies to scientific readers.

- The scientific reader as a **code breaker** successfully recognises and decodes scientific text. This includes the correct meaning of words associated with scientific ideas.
- The scientific reader as a **meaning maker** uses their background knowledge and understanding to make meaning, comparing their personal experiences with those presented in the text.
- The scientific reader as a **text user** uses the right type of text for the right context and purpose
- The scientific reader as a t**ext critic** or text analyst understands that most text is written with a particular point of view. They will learn to recognise bias and to identify ways in which the readers, viewers, or listeners are influenced. As literate scientists, they will learn the importance of reliable and valid evidence in the support of argument.

Numeric skills are necessary to understand, analyse and evaluate scientific material. As students study science, they have the opportunity to develop skills in calculation, reasoning and problem solving, data handling and graphicacy. Through studying science, students will come to appreciate the fun of exploring mathematical problems in the context of a scientific idea and the satisfaction of arriving at a solution. They will learn the mathematical meaning of common words and phrases, which will help them as they relate their mathematical understanding to everyday contexts.

By engaging in scientific inquiry, students develop their understanding of data analysis by collecting, representing, describing, and interpreting numerical data, and learning how to deal with variations in this data. As they investigate familiar situations through a scientific lens, they learn to formulate questions and draw conclusions from data. Through this they gain an understanding of data analysis as a tool for learning about the world.

Each strand of Junior Certificate Mathematics includes common learning outcomes related to synthesis and problem solving skills.

Students should be able to

- *explore patterns and formulate conjectures*
- *explain findings*
- *justify conclusions*
- *communicate mathematics verbally and in written form*
- *apply their knowledge and skills to solve problems in familiar and unfamiliar contexts*
- *analyse information presented verbally and translate it into mathematical form*
- *devise, select and use appropriate mathematical models, formulae or techniques to process information and to draw relevant conclusions* (NCCA, pgs16, 20, 25, 29, 31)

These skills will be reinforced and further developed as students engage in scientific inquiry.

Practical activities

There is a strong belief that student practical work leads to better learning. However many research studies have shown that students often do not learn what was intended from a practical activity (Millar, R. in press). This has led some science educators to question the contribution of practical work to learning (Osborne, J.1998, Hodson, D.1991). Students benefit from engaging in practical activities. However, in considering the type (confirmatory or open-ended) and extent of the practical activities in the junior cycle science specification, a key consideration will be the effectiveness of each activity in developing students' understanding.

Practical activities differ considerably in what they ask students to do and what they are trying to teach. The fundamental purpose of much practical work in science is to help students to make links between objects and observables (things they can see and handle) and the ideas (that they cannot observe directly). Students learn when the activity is not only *hands on* but also *minds on*. It is important to consider what the activity requires students to *do* with ideas, as well as with objects and materials and how well the activity supports their learning of ideas and not just their ability to manipulate objects or recall observable events (Reiss, M, Abrahams, I.Z & Sharpe, RM. 2012).

Use of ICT

The process of measurement is an integral feature of science investigation. Measurement combines procedural skills, such as controlling variables, evaluating reliability, precision and accuracy; and operational skills, such as manipulation of apparatus, use of measuring instruments and reading scales. Technology automates the process of data collection and graphical representation of data allowing for stronger focus on the thinking behind the doing. ICT can be used to explore, illustrate and develop scientific concepts in innovative ways. Simulations can be used to investigate contexts that would be impossible in a school laboratory. Sensors allow for rapid data collection and graphing which encourages higher order thinking and allows time for students to evaluate their investigations and explore *what would happen if* situations. More generally, software and devices now allow rapid analysis of data from sensors or from manually entered data. This moves students from routine graphing practices to consideration of the meaning of the results, testing of various possible plots and further investigation.

Section summary
21st century science curricula emphasise the development of an understanding of the *nature of science*. How they are structured to achieve this development varies widely, yet their design shares many similarities. The development of literacy and numeracy skills is a core element of science learning. Language skill is necessary to read and interpret scientific material. Numeric skills are necessary to understand, analyse and evaluate scientific material. In considering the type and extent of the practical activities in the specification for Junior Cycle Science a key consideration will be the effectiveness of each activity in developing students' understanding. ICT is an invaluable tool that students use to explore scientific concepts and deepen their understanding of the connections between practical science and the theory that underpins it.

8. Science specification in the new Junior Cycle

While some may have distinct characteristics, arising from the area of learning involved, all junior cycle specifications, for subjects and short courses, will have a number of features in common. They will

- be outcomes based
- reflect a continuum of learning with a focus on learner progression
- set out clear expectations for learning
- provide examples of those expectations
- include a focus on literacy, numeracy and key skills
- strive for clarity in language and for consistency in terminology.

To improve the connection with learning and teaching in primary school, these features are shared with the Primary Curriculum. The specification for each junior cycle subject and short course will include:

Introduction to junior cycle	This will be common to all specifications and will summarise the main features of the *Framework for Junior Cycle*.
Aim	A concise aim for the subject or short course will be set out.
Rationale	This will describe the nature and purpose of the subject or short course, as well as the general demands and capacities it will place on and require of students.
Links with ▪ Statements of learning ▪ Literacy and numeracy ▪ Key skills	How the subject or short course is linked to central features of learning and teaching at junior cycle will be highlighted and explained.

Overview ▪ Strands ▪ Learning Outcomes	An overview of the subject or short course will illustrate how it is organised and set out the learning involved in strands and learning outcomes.
Expectations for students	These will be linked with groups of learning outcomes of the subject or short course online and will relate to examples of student work. The examples will be annotated, explaining whether the work is in line with, ahead of, or behind expectations for students.
Assessment and certification	This section will refer to both formative and summative assessment. It will outline the assessment component/s for which students will present evidence of learning that can contribute towards junior cycle certification. A description of the schoolwork component of assessment, and the examination component, will be provided. The assessment tasks involved in the schoolwork component and the features of quality criteria used to assess these tasks will also be set out. These will be supplemented by other detailed assessment material and arrangements, from the SEC and NCCA, at appropriate times during the junior cycle.

9. Brief for the review of Junior Cycle Science

The review of Junior Cycle Science will lead to the production of a specification in line with the template above.

The principles for junior cycle education as they appear in the Framework for Junior Cycle will inform key decisions made in the development of the specification for Science. In its work, the development group will be conscious of the extent to which the specification relates to various statements of learning in the Framework and in that context, how it might assist a school in planning and evaluating their junior cycle programme.

The specification will be at a common level.

It will be designed to be taught in a minimum of 200 hours.

It will be structured or organised around strands and learning outcomes.

The key skills of junior cycle, as appropriate, will be embedded in the learning outcomes of the specification.

The skills of literacy and numeracy will be promoted through specific aspects of the specification.

It will be completed for Autumn 2014.

The development of the new specification for Junior Cycle Science will take account of current research and developments within the field of science education, particularly the emerging understanding of the *Nature of Science*.

The development of the new specification will address continuity and progression. It will consider whether first year Science should be taught as a common introductory course (CIC), with a particular focus on consolidating learning from primary school and on the development of students' understanding of the *Nature of Science*. Some consideration should be given to the development of bridging units to be commenced by students in sixth class and completed at the start of first year.

More specifically, the development of the new specification will address

- the purposes of junior cycle science, making them transparent and evident to students, teachers and parents in the specification
- How the specification, in its presentation and language register, can be strongly student-centred, having a clear focus on what the students can do to develop and demonstrate their scientific literacy and achievements
- How inquiry-based teaching and learning should be promoted
- How the course will be organised; whether it will continue to be structured around the three major areas of science: biology, chemistry and physics, or around thematic units of science
- Continuity and progression: how to connect with and build on primary science as well as provide a platform for the study of science in senior cycle
- How personal and societal interests about science can be used as a reference point from which the curriculum is specified
- The ongoing assessment of student learning as well as the components related to assessment for certification
- How to highlight the relationship between science and technology
- The emphasis placed on discussion and analysis of scientific, environmental and sustainability issues that permeate contemporary life
- How to tap into the natural curiosity of students and their desire to create and work in practical ways through practical activity.

The work of the subject Development Group will be based, in the first instance, on this brief. In the course of its work and discussions, elaborations of some of these points and additional points may be added to the brief.

From a long-term perspective all science curricula are in a constant state of change. The success of the new specification will be measured by the extent to which junior cycle students and their teachers become more excited about science and how science works.

References

Atkin, M & Black, P. (2003). Inside science education reform: A history of curricular and policy change. New York: Teachers College Press.

Atkin, M., Black, P., Britton, E & Raizen, S. (1996). A global revolution in science, mathamatics and technology education, *Education Week* , April 10.

Burke, N., Condon, N. & McNaboe, J. (2013). Monitoring Ireland's Skills Supply: Trends in Education and Training Outputs. Retrieved July 26, 2013 from http://www.skillsireland.ie/media/05072013-Monitoring_Ireland's_Skills_Supply_2013-Publication.pdf

Cheevers, Carly, Eivers, Eemer & Shiel Gerry. (2006). Implementing the revised Junior Certificate Science Syllabus: What teachers said. Retrieved March 25, 2013 from http://www.education.ie/en/Publications/Inspection-Reports-Publications/Evaluation-Reports-Guidelines/insp_jcssreview_pdf.pdf

Clerkin, A., Eivers, E. (2013). National Schools, international contexts: Beyond the PIRLS and TIMSS test results. Dublin: Educational Research Centre.

Cosgrove, J., Shiel, G., Sofroniou, N., Zastrutzki, S., & Shortt, F. (2005). Education for life: The achievements of 15-year-olds in Ireland in the second cycle of PISA. Dublin: Educational Research Centre.

Curriculum for excellence: sciences, Experiences and outcomes. Retrieved May 12, 2013 from http://www.educationscotland.gov.uk/Images/sciences_experiences_outcomes_tcm4-539890.pdf

Davis, S.L., & Buckendahl, C.W. (2011) Incorporating Cognitive Demand in Credentialing Examinations. In G. Schraw & D.R. Robinson (Eds) Assessment of Higher Order Thinking Skills (pp.327-358). North Carolina: IAP

Department of Education and Science. (2003). Junior Certificate Science syllabus (Ordinary level and Higher level). Retrieved March 25, 2013 from http://www.curriculumonline.ie/uploadedfiles/JC/SciencesyllabusJC.pdf

Dept. of Children and Youth Affairs. (2011).A Consultation with young people on reform of the JC. Government Publications, Dublin.

European Commission. (1995). White paper on education and training:Teaching and learning-Towards the learning society (white Paper). Luxembourg: Office for Official Publications in European Countries.

Harlen, W (Ed) (2010) Principles and Big Ideas of Science Education. Hatfield: ASE.

Hirsch, D. (1999). Innovating schools: Schooling for tomorrow. Paris: OECD publishing.

Hodson, D. (1991). Practical work in science: Time for a reappraisal. *Studies in Science Education*, 19, 175-184.

Hodson, D. (1993). Towards a more critical approach to practical work in school science, *Studies in Science Education*, 22, p.106.
http://www.curriculumonline.ie/uploadedfiles/JC/JCScienceTGlin.pdf
http://www.york.ac.uk/depts/educ/research/ResearchPaperSeries/index.htm

Lederman, N., Abd-el-Khalick, F., Bell, R.L., & Schwartz, R.S. (2002). Views of Nature of Science Questionnaire: Towards valid and meaningful assessment of learners' conceptions of the nature of science. Journal of Research in Science Teaching, 39, 497 –521.

Luke, A. & Freebody, P. (1999). Further notes on the four resources model. Reading online,3.Retrieved March 26th 2013 from
http://www.readingonline.org/research/lukefreebody.html

Matthews, M. (1995). Constructivism and New Zealand science education. Auckland: Dunmore Press.

Matthews, Philip. (2007). The Relevance of Science Education in Ireland. Dublin: Royal Irish Academy. Available at http://roseproject.no/network/countries/ireland/irl-matthews-rose-report.pdf

McComas, W.F., & Olson, J.K. (1998). The nature of science in international science education standards documents. In W.F. McComas (Ed.), The nature of science in science education: Rationales and strategies (pp. 41–52). Dordrecht: Kluwer.

Millar, R. & Osborne, J.F. (Eds.). (1998). Beyond 2000: Science education for the future. London: King's College London.

Millar, R. (2009). *Analysing practical activities to assess and improve effectiveness: The Practical Activity Analysis Inventory (PAAI).* York: Centre for Innovation and Research in Science Education, University of York. Retrieved May 26, 2013 from

Millar, R. (2011): Reviewing the National Curriculum for science: opportunities and challenges. Curriculum Journal, 22:2, 167-185

Millar, R. (2012). Starting from outcomes: Using assessment to drive improvement in practice. *Education in Science.* No. 246, February, p6-8.

Murphy, C., Varley, J. & Veale, O. (2008). Science in Primary Schools, Phase 1. National Council for Curriculum and Assessment. Retrieved May 13th 2013 from http://www.ncca.ie/en/Publications/Reports/Science_in_Primary_Schools,Phase_1.pdf

Murphy, C., Varley, J. & Veale, O. (2008). Science in Primary Schools, Phase 2. National Council for Curriculum and Assessment. Retrieved May 14th 2013 from http://www.ncca.ie/en/Publications/Reports/Science_in_Primary_Schools,Phase_2.pdf

European Commission, 2007. Science Education Now: A Renewed Pedagogy for the Future of Europe. Brussels: European Commission.
Retrieved May 31st 2013:

http://ec.europa.eu/research/science-society/document_library/pdf_06/report-rocard-on-science-education_en.pdf

National Council for Curriculum and Assessment. (2006). Junior Certificate Science, Draft Guidelines for Teachers. Retrieved May 13, 2013 from http://www.curriculumonline.ie/uploadedfiles/JC/JCScienceTGlin.pdf

National Council for Curriculum and Assessment (2013) Junior Certificate Mathematics Syllabus. Available at: http://www.ncca.ie/en/Curriculum_and_Assessment/Post-Primary_Education/Project_Maths/Syllabuses_and_Assessment/JC_Maths_English_2013.pdf

National Research Council. (2012). A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas. Washington, DC: The National Academies Press.

National Research Council. (2012). Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas. Committee on a Conceptual Framework for New K-12 Science Education Standards. Boards on Science Education, Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.

Next Generation Science Standards. National Academic Press Retrieved May 12, 2013. http://www.nextgenscience.org/next-generation-science-standards

Northern Ireland Curriculum, Key Stage 3 Non Statutory Guidance for Science. Retrieved May 12, 2013. http://www.nicurriculum.org.uk/docs/key_stage_3/areas_of_learning/non_statutory/ks3_science_ns_guidance.pdf

OECD/CERI,(2005). Formative assessment: improving learning in secondary classrooms. Paris: OECD publications.

Orpwood, G. (2001). The role of assessment in Science curriculum reform. *Assessment in Education*, Vol. 8, No. 2, 2001, pp135-151.

Osborne, J & Dillon. J.,(2008). Science education in Europe: critical reflection. London: The Nuffield Foundation.

Osborne, J. (1998). Science education without a laboratory? In J.J. Wellington (Ed.), *Practical work in school science. Which way now?* (pp. 156-173). London: Routledge.

Reiss, M, Abrahams, IZ & Sharpe, RM. 2012. Improving the assessment of practical work in school science. Research report for the Gatesby Charitable Foundation.

Roberts, D.A. 2007. Scientific literacy/science literacy. In *Handbook of research on science education*, ed. S.K. Abelland N.G. Lederman, 729-780. New Jersey: Lawrence Erlbaum Associates, Inc.

Schreiner, C. & Sjoberg, S. (2007). Science education and youth's identify construction – Two incompatible projects? In D. Corrigan, J Dillon, & R.F. Gunstone (Eds.), The re-emergence of values in the science curriculum. Rotterdam: Sense publisher.

Science, Guidance for Key Stages 2 and 3, Department for Children, Education, Lifelong. Learning. Retrieved May 12, 2013.
http://wales.gov.uk/docs/dcells/publications/110331scienceguideen.pdf

Smith, M., Lederman, N.G., Bell, R., McComas, W.F., & Clough, M. (1997). How great is the disagreement about the nature of science: A response to Alters. Journal of Research in Science Teaching, 34, 1101 –1103.

State Examinations Commission. (2006). Chief Examiners Report, Junior Certificate Examination 2006: Science. Retrieved May 13, 2013 from http://examinations.ie/archive/examiners_reports/cer_2006/JC_Sc_CE_Report_2006Edited.pdf

State Examinations Commission. (2010). Chief Examiners Report, Junior Certificate Examination 2010: Science. Retrieved May 13, 2013 from http://www.examinations.ie/archive/examiners_reports/JC_Science_CE_2010.pdf

The Department of Education and Science. (2002). Task Force on the Physical Sciences - Report and recommendations. Retrieved March 25, 2013 from http://www.dcya.gov.ie/docsdb/documents/physical_sciences_report.pdf?language=EN.

Department of Education and Science. (2008). Looking at Junior Cycle Science. Retrieved May 12, 2013 http://www.sdpi.ie/inspectorate/insp_looking_at_science_08.pdf

The Next Generation Science Standards (2013). Retrieved May 1, 2013 from http://www.nextgenscience.org/sites/ngss/files/Final%20Release%20NGSS%20Front%20Matter%20.pdf

The Ontario Curriculum Grades 1-8, Science, Ministry of Education. Retrieved May 12, 2013.
http://www.edu.gov.on.ca/eng/curriculum/elementary/scientec18currb.pdf

Wiggin, G & McTighe, J. (2006). Understanding by design, 2nd edn. Upper Saddle River, NJ: Pearson.

Appendix 1

Comparative information on the structure and learning outcomes of science curricula in other countries.

The integration of the various dimensions of science education is a common theme through curriculum specifications in other countries. The following examples offer some perspectives of curriculum structure from the USA, Wales, Scotland, Tasmania, Ontario and Northern Ireland.

United States of America

In the US there was criticism that American science performance was lagging as the economy becomes increasingly high tech and the 1996 Science Education Standards was doing little to resolve this. This led to the development of the Next Generation of Science Standards (NGSS) which was released in April 2013. The development process was initiated by a consortium including The National Research Council, The National Science Teachers Association and The American Association for the Advancement of Science. The process was conducted over a two year period, during which time it was advised by expert panels of scientists, engineers and educators, and required considerable financial resources. This work culminated in the release of the NGSS in April 2013. While they have not been enacted into the classroom to date, they do provide a very interesting response to the genuine concerns held in the US about the science education they are providing in primary and post-primary schools.

The Next Generation Science Standards have been expressed as performance expectations which are assessable statements of what students should know and be able to do to demonstrate that they have met the standard. Each standard has three dimensions:

- Scientific practices: the skills and knowledge to engage in scientific investigations e.g. asking questions, developing and using models, etc.
- Crosscutting concepts: unifying concepts and processes that provide students with connections and intellectual tools that can enrich students' applications of scientific practices e.g. patterns, cause and effect, etc.

- Disciplinary Core Ideas (DCIs) in four disciplinary areas: physical sciences; life sciences; earth and space sciences; and engineering, technology and applications of science.

The integration of these three dimensions provides students with a context for learning the content knowledge of science, how this science knowledge is acquired and how the sciences are connected through crosscutting concepts. Hence, students are required to operate at the intersection of practice, content and connection.

One of the key features of the NGSS is that it is built on the notion that learning is a developmental progression; this is operationalised in the NGSS by placing an emphasis on

- the fact that crosscutting concepts and scientific practices are designed to be taught in context
- a coherent progression of knowledge of science concepts from grade band to grade band; Table 6 below is a summary of how it is envisaged that the crosscutting concept of patterns would increase in complexity and sophistication.

Table 6: Progression across the grade bands of the concept: Patterns[2].

Progression Across the Grades	Performance Expectation from the NGSS
In grades K-2, children recognize that patterns in the natural and human designed world can be observed, used to describe phenomena, and used as evidence.	1-ESS1-1. Use observations of the sun, moon, and stars to describe patterns that can be predicted.
In grades 3-5, students identify similarities and differences in order to sort and classify natural objects and designed products. They identify patterns related to time, including simple rates of change and cycles, and to use these patterns to make predictions.	4-PS4-1. Develop a model of waves to describe patterns in terms of amplitude and wavelength and that waves can cause objects to move.
In grades 6-8, students recognize that macroscopic patterns are related to the nature of microscopic and atomic-level structure. They identify patterns in rates of change and other numerical relationships that provide information about natural and human designed systems. They use patterns to identify cause and effect relationships, and use graphs and charts to identify patterns in data.	MS-LS4-1. Analyze and interpret data for patterns in the fossil record that document the existence, diversity, extinction, and change of life forms throughout the history of life on Earth under the assumption that natural laws operate today as in the past.

- reduced content knowledge (DCIs); with a particular focus on deeper understanding and application of content. One criterion used for deciding on the DCIs was that the content would *be teachable and learnable over multiple grades at increasing levels of*

[2] Next Generation Science Standards. National Academic Press.

depth and sophistication (NGSS, 2013). Hence, there is also progression of DCIs across the grade bands, as illustrated in Table 7 below.

Table 7: NGSS: Progression across the grade bands of the DCI Structure and function[3]

Life Science Progression

INCREASING SOPHISTICATION OF STUDENT THINKING

	K-2	3-5	6-8	9-12
LS1.A Structure and function	All organisms have external parts that they use to perform daily functions.	Organisms have both internal and external macroscopic structures that allow for growth, survival, behavior, and reproduction.	All living things are made up of cells. In organisms, cells work together to form tissues and organs that are specialized for particular body functions.	Systems of specialized cells within organisms help perform essential functions of life. Any one system in an organism is made up of numerous parts. Feedback mechanisms maintain an organism's internal conditions within certain limits and mediate behaviors.

The NGSS acknowledges that there is no one teaching, learning or assessment approach that defines how to integrate the three dimensions (Table 8). Students cannot fully understand scientific ideas without understanding the inquiry and the discourses that took place in the development of the ideas. At the same time, they cannot learn or show competence in inquiry and scientific practices except in the context of specific content. To ensure that the dimensions are fully integrated, the NGSS suggests that standards and performance expectations are designed to gather evidence of students' ability to apply the practices and their understanding of the cross-cutting concepts in the contexts of specific applications in multidisciplinary areas.

[3] Next Generation Science Standards. National Academic Press.

Table 8: NGSS: Three dimensions of the K-12 framework[4]

THE THREE DIMENSIONS OF THE FRAMEWORK

1 Scientific and Engineering Practices

1. Asking questions (for science) and defining problems (for engineering)
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations (for science) and designing solutions (for engineering)
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

2 Crosscutting Concepts

1. Patterns
2. Cause and effect: Mechanism and explanation
3. Scale, proportion, and quantity
4. Systems and system models
5. Energy and matter: Flows, cycles, and conservation
6. Structure and function
7. Stability and change

3 Disciplinary Core Ideas

Physical Sciences
PS1: Matter and its interactions
PS2: Motion and stability: Forces and interactions
PS3: Energy
PS4: Waves and their applications in technologies for information transfer

Life Sciences
LS1: From molecules to organisms: Structures and processes
LS2: Ecosystems: Interactions, energy, and dynamics
LS3: Heredity: Inheritance and variation of traits
LS4: Biological evolution: Unity and diversity

Earth and Space Sciences
ESS1: Earth's place in the universe
ESS2: Earth's systems
ESS3: Earth and human activity

Engineering, Technology, and Applications of Science
ETS1: Engineering design
ETS2: Links among engineering, technology, science, and society

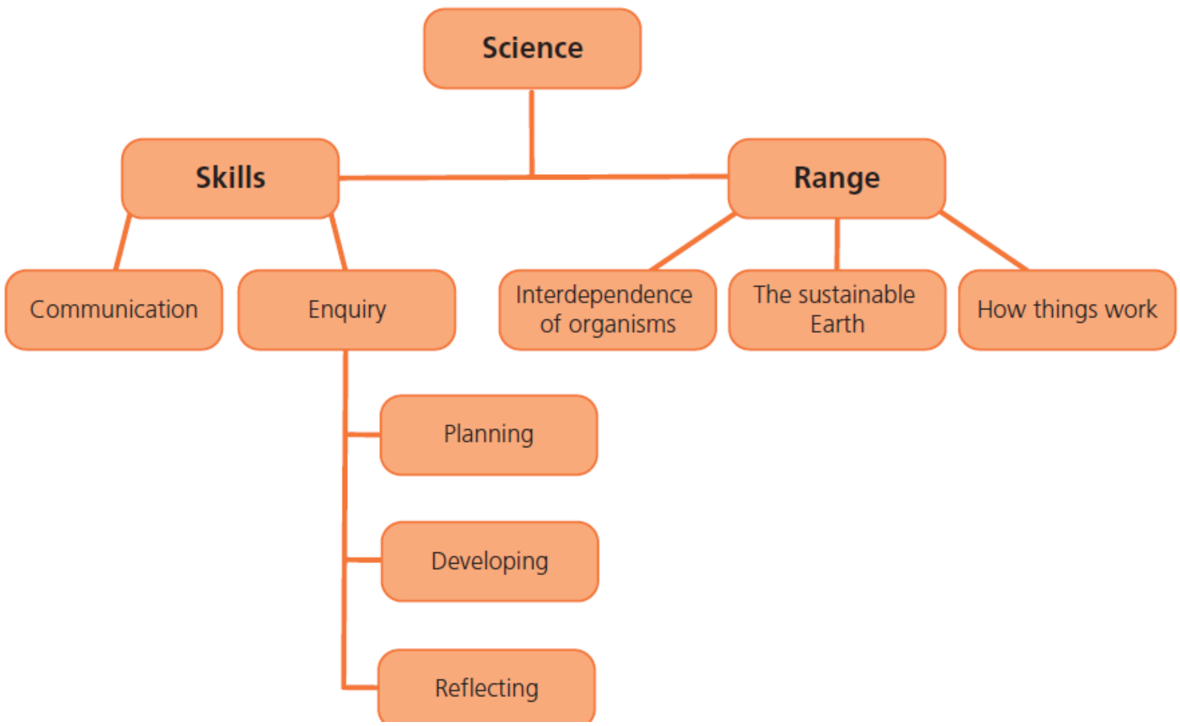
Wales

In the Welsh curriculum the progression in science is detailed in terms of how students develop skills. A programme of study is set out for each of the elements comprising *Skills (for process of science) and Range (specifying actual content).* The Skills section of the science programme of study is set out under the headings *communication* and *enquiry*, with the levels

[4] Next Generation Science Standards. National Academic Press.

of inquiry set out under the headings **planning, developing and reflecting**. The Range describes the science content which provides context through which students develop the specified skills. It is up to schools to determine the number and context of such opportunities within their curriculum overview/curriculum planning. The specification indicates by icons where particular opportunities arise for students to develop their **thinking,** **communication**, **number** and **ICT** across the Range.

Figure 1 Welsh science curriculum: structure of the science programme of study[5]



The progression in skills is outlined for each key stage. Level descriptions describe the performance expectations that students working at a particular level should characteristically demonstrate. In deciding on a pupil's level of attainment at the end of a key stage, teachers judge which description best fits the pupil's performance.

[5] Science, Guidance for Key Stages 2 and 3, Dept for Children, Education, Lifelong. Learning.

Scotland

The sciences curriculum area within *Curriculum for Excellence* was designed to meet the challenges of ensuring that while every child and young person needs to develop a secure understanding of important scientific concepts, their experience of the sciences in school must develop a lifelong interest in science and its applications.

To meet these challenges, content was updated from the previous curriculum and account was taken of research evidence on learning in science and of international comparisons. As a result, there is a strong emphasis on the development of understanding and on critical evaluation, and expectations in some areas were raised.

In secondary schools in Scotland, students can study the sciences through discrete subjects, integrated sciences, interdisciplinary learning or a blend of these. Secondary schools are increasingly developing innovative approaches to ensure young people can avail of their entitlement to a broad general education. In the Scottish curriculum for excellence, the science framework provides a range of different contexts for learning which draw on important aspects of everyday life and work. The framework is described in experiences and outcomes which are designed to tap into students' natural curiosity and their desire to create and work in practical ways. The key concepts have been clearly identified using five organisers:

- Planet Earth
- Forces, electricity and waves
- Biological systems
- Materials
- Topical science.

The content detailed in the framework is limited, but as students progress through lower secondary education, they engage with more detailed descriptions and explanations of increasingly complex scientific contexts and concepts by using a wider range of scientific language, formulae and equations and by presenting, analysing and interpreting more complex evidence to draw conclusions and make sense of scientific ideas. The level of achievement at the fourth level has been designed to approximate to that associated with SCQF level 4. As in other curriculum areas, the fourth level experiences and outcomes provide possibilities for choice: it is not intended that any individual students' programme of learning would include all of the fourth level outcomes.

Schools and teachers offer different combinations of the experiences and outcomes to provide programmes that meet students' needs and provide a sound basis for more advanced study within the discrete sciences

Australian National Curriculum

In the Australian Curriculum; Science has three interrelated strands: Science Understanding, Science as a Human Endeavour and Science Inquiry Skills.

Together, the three strands of the science curriculum provide students with understanding, knowledge and skills through which they can develop a scientific view of the world. Students are challenged to explore science, its concepts, nature and uses through clearly described inquiry processes.

Figure 2: Australian Science curriculum: Content structure[6]

The *Science Understanding* strand comprises four sub-strands: Biological sciences, Chemical sciences, Earth and spaces sciences, Physical sciences. The content is described by year level.
The *Science as a Human Endeavour* strand has two sub-strands: Nature and development of science and Use and influence of science. This strand highlights the development of science as a unique way of knowing and doing, and the role of science in contemporary decision making and problem solving. The content is described over two year bands.
The *Science Inquiry Skills* strand has five sub-strands that are described over two year bands. This strand is concerned with evaluating claims, investigating ideas, solving problems, drawing valid conclusions and developing evidence-based arguments.The sub-strands are: Questioning and predicting, Planning and conducting, Processing and analysing data information, Evaluating, Communicating.

[6] Australian Curriculum, Assessment and Reporting Authority.

It is not intended that each strand be taught separately. In the Australian Curriculum: Science is intended to be taught in an integrated way. The content descriptions of the three strands have been written so that at each year this integration is possible. These content descriptors describe the knowledge, concepts, skills and processes that teachers are expected to teach and students are expected to learn.

Ontario Canada

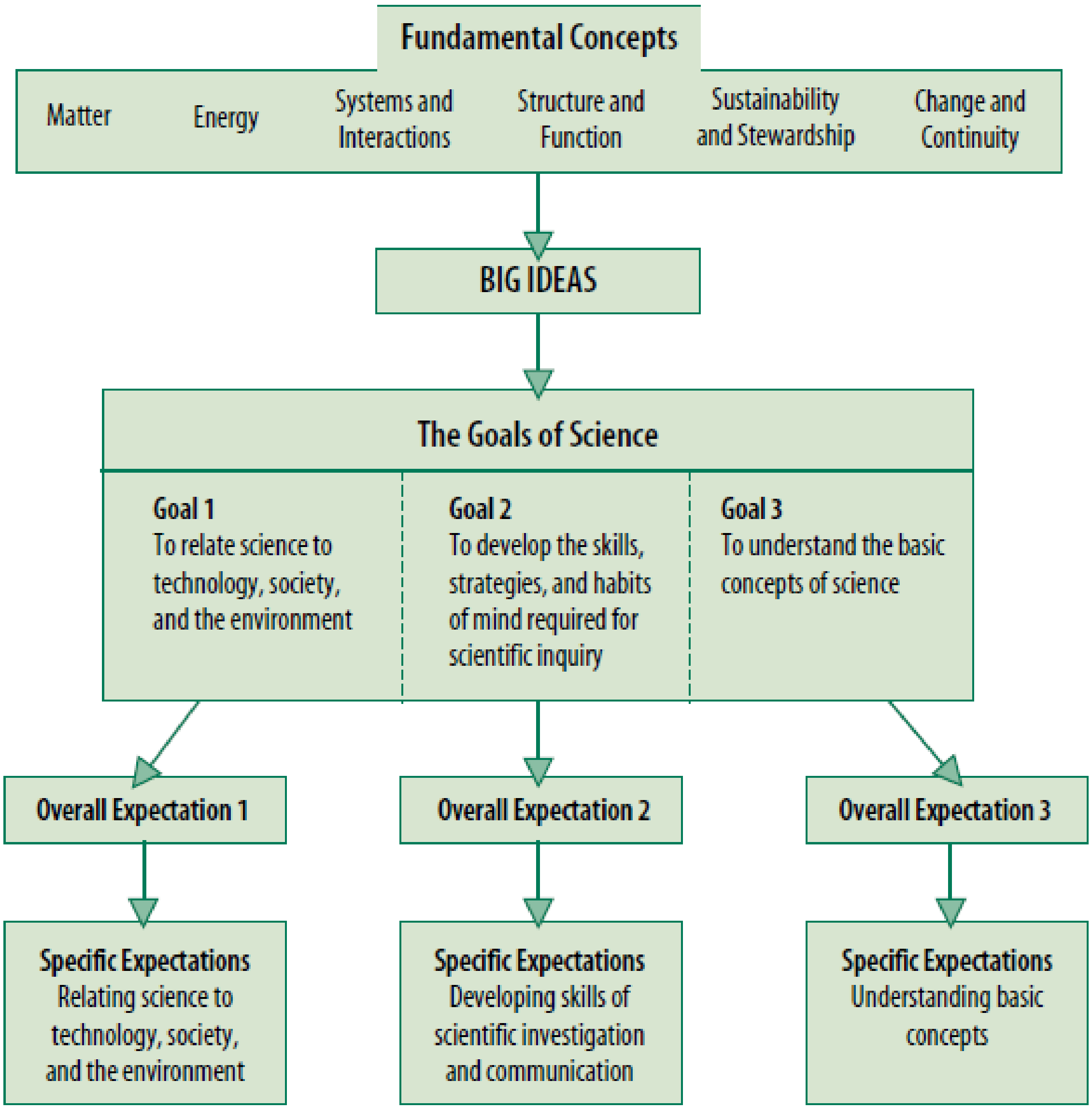
In the Ontario Science curriculum, fundamental concepts provide context for students throughout their progression in school. Fundamental concepts are key ideas that provide a framework for the acquisition of all scientific and technological knowledge. The fundamental concepts are ***matter, energy systems and interactions, structure and function, sustainability and stewardship***, and ***change and continuity***.

As students progress through the curriculum from grades 1 to 12, they extend and deepen their understanding of these fundamental concepts and learn to apply their understanding with increasing sophistication.

Each course within the curriculum contains a list of ‘big ideas’ to be covered. Big ideas are the broad, important understandings that students should retain long after they have forgotten many of the details of what they have studied in the classroom. For example, the Science and Technology course for grades 1-8 has four strands: understanding life systems; understanding structures and mechanisms; understanding matter and energy; and understanding Earth and space systems. Each strand has a list of big ideas to be covered. For each of the big ideas, there are learning outcomes (specific expectations) in each of the following areas categorised by the three goals of Science:

- Relating Science and Technology to Society and the Environment
- Developing Investigation and Communication Skills
- Understanding Basic Concepts

Figure 2. Ontario science curriculum: relationship between the fundamental concepts, big ideas, the goals of the science program, and the overall and specific expectations[7]



[7] The Ontario Curriculum Grades 1-8, Science, Ministry of Education.

For example:

Grade: Eighth Grade (first year equivalent).

Fundamental concepts: Systems and interactions; structure and function.

Strand: Understanding life systems.

Big idea: Cells are the basis of life.

Relating Science and Technology to Society and the Environment: students are able t*o* assess the potential that our understanding of cells and cell processes has for both beneficial and harmful effects on human health and the environment, taking different perspectives into account *(e.g., the perspectives of farmers, pesticide manufacturers, people with life-threatening illnesses).*

Developing Investigation and Communication Skills: students are able to use scientific inquiry/experimentation skills to investigate the processes of osmosis and diffusion

Understanding Basic Concepts: students are able to compare the structure and function of plant and animal cells

Form grade 9 (equivalent to second year) students can choose between two science courses: Academic Science and Applied Science. The 'big ideas' to be covered in these courses are listed under the strands: biology, chemistry, physics and Earth and space science. The Applied Science course focuses on applying their knowledge of science to everyday situations, whereas Academic Science focuses on helping students to relate science to technology, society, and the environment.

Northern Ireland

The three objectives of the Northern Ireland Curriculum are:

- to develop students as individuals,
- to develop students as contributors to society,
- to develop students as contributors to the economy and environment.

These curriculum objectives are broken down into key elements. Each subject must contribute to all key elements across the key stage.

Table 10 below shows how each curriculum objective is linked to specific key elements.[8]

The Northern Ireland Curriculum should provide relevant opportunities to help each pupil develop as:		
Objective 1 An individual	Objective 2 A contributor to society	Objective 3 A contributor to the economy and the environment
Key Elements Personal Understanding Mutual Understanding Personal Health Moral Character Spiritual Awareness	Key Elements Citizenship Cultural Understanding Media Awareness Ethical Awareness	Key Elements Employability Economic awareness Education for Sustainable Development

The key elements are used to make meaningful links with other subjects and to promote coherence across the whole curriculum.

The statutory requirements for Science in the Northern Ireland Curriculum outline the Knowledge, Understanding and Skills in Science that students are to develop in Key Stage 3. The content that students are to learn about is divided into four sections: Organisms and Health, Chemical and material behaviour, Forces and energy, Earth and Universe. These headings are not accompanied by an exhaustive list of learning outcomes. While covering the statutory requirements, teachers have flexibility to follow their own and their pupils' interests.

[8] Northern Ireland Curriculum, Key Stage 3 Non Statutory Guidance for Science.

The curriculum objectives provide the contexts through which the mandatory requirements for developing students' knowledge, understanding and skills can be achieved.This approach offers teachers flexibility to use the statutory requirement to devise their own schemes of work that follow their students' needs and interests and are real and relevant to the lives of young people. Teachers also have the opportunity to combine aspects of Biology, Chemistry and Physics into thematic units of work, for example air and breathing, light and how we see, etc. A school could decide to offer thematic units that crossed subject boundaries or could develop subject specific units or adopt a combination of both.

There is a focus on providing opportunities for developing Cross-Curricular Skills and Thinking Skills/ Personal Capabilities to deepen understanding of a particular concept or context in Science.

New Zealand

In the New Zealand Science curriculum is designed to enable students to:

- develop an understanding of the world, built on current scientific theories
- learn that science involves particular processes and ways of developing and organising knowledge and that these continue to evolve
- use their current scientific knowledge and skills for problem solving and developing further knowledge
- use scientific knowledge and skills to make informed decisions about the communication, application, and implications of science as these relate to their own lives and cultures and to the sustainability of the environment.

The fundamental aims of the science curriculum are expressed as a series of achievement aims, grouped by strand. The **nature of science** strand is the overarching, unifying strand. Through it, students learn what science is and how scientists work. It has four themes which tease out ideas about the nature of science, namely: Understanding about science, Investigating in science, Communicating in science and Participating and Contributing. The other strands; living world, physical world, planet earth and beyond; provide the contexts for learning to enable students to develop their understanding of the nature of science.

The **living world strand** is about living things and how they interact with each other and the environment. The **planet earth and beyond** strand is about the interconnecting systems and processes of the Earth, the other parts of the solar system, and the universe beyond. The **physical world** strand provides explanations for a wide range of physical phenomena, including light, sound, heat, electricity, magnetism, waves, forces, and motion, united by the concept of energy, which is transformed from one form to another without loss.

The achievement objectives at each level are derived from the aims and are similarly grouped by strand. There is clear progression in the development of the achievement objectives as a student progresses through the levels.

Appendix 2

Information on the 1999 Primary Science Curriculum.

The 1999 Primary Science Curriculum was implemented in schools in Sept 2003 after a period of inservice and support for teachers and schools from 2000-2003. Science is now compulsory for all children from junior infants to sixth class.

Primary science involves helping children develop basic scientific ideas and understanding through the skills of *working scientifically* and *designing and making* which will enable them to explore and investigate their world. In well-planned, practical investigations children's natural curiosity is channelled and they are equipped with the strategies and processes to develop scientific ideas and concepts. Knowledge and understanding for each age group is presented in four **strands**: Living things, Energy and forces, Materials and Environmental awareness and care. Each of these strands is further divided into **strand units** as shown in Table 1

Table 1 Summary of strands and strand units in Primary Science Curriculum[9]

	Living things	**Energy and forces**	**Materials**	**Environmental awareness and care**
Infants	▪ *Myself* ▪ *Plants and animals*	▪ *Light* ▪ *Sound* ▪ *Heat* ▪ *Magnetism and electricity* ▪ *Forces*	▪ *Properties and characteristics* ▪ *Materials and change*	▪ *Caring for my locality*
1st and 2nd classes	▪ *Myself* ▪ *Plants and animals*	▪ *Light* ▪ *Sound* ▪ *Heat* ▪ *Magnetism and electricity* ▪ *Forces*	▪ *Properties and characteristics* ▪ *Materials and change*	▪ *Caring for my locality*
3rd and 4th classes	▪ *Human life* ▪ *Plants and animals*	▪ *Light* ▪ *Sound* ▪ *Heat* ▪ *Magnetism and electricity* ▪ *Forces*	▪ *Properties and characteristics* ▪ *Materials and change*	▪ *Environmental awareness* ▪ *Science and the environment* ▪ *Caring for the environment*
5th and 6th classes	▪ *Human life* ▪ *Plants and animals*	▪ *Light* ▪ *Sound* ▪ *Heat* ▪ *Magnetism and electricity* ▪ *Forces*	▪ *Properties and characteristics* ▪ *Materials and change*	▪ *Environmental awareness* ▪ *Science and the environment* ▪ *Caring for the environment*

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In addition, there are a number of science skills that the children are expected to develop over the course of their eight years in primary school. Table 2 summarises these skills.

Table 2 Summary of working scientifically and designing and making skills in the Primary Science Curriculum[10]

	Working scientifically	Designing and making
Infants	▪ *Questioning* ▪ *Observing* ▪ *Predicting* ▪ *Investigating and experimenting* ▪ *Estimating and measuring* ▪ *Analysing* *Sorting and classifying* ▪ *Recording and communicating*	▪ *Exploring* ▪ *Planning* ▪ *Making* ▪ *Evaluating*
1st and 2nd classes	▪ *Questioning* ▪ *Observing* ▪ *Predicting* ▪ *Investigating and experimenting* ▪ *Estimating and measuring* ▪ *Analysing* *Sorting and classifying* *Recognising patterns* *Interpreting* ▪ *Recording and communicating*	▪ *Exploring* ▪ *Planning* ▪ *Making* ▪ *Evaluating*
3rd and 4th classes	▪ *Questioning* ▪ *Observing* ▪ *Predicting* ▪ *Investigating and experimenting* ▪ *Estimating and measuring* ▪ *Analysing* *Sorting and classifying* *Recognising patterns* *Interpreting* ▪ *Recording and communicating*	▪ *Exploring* ▪ *Planning* ▪ *Making* ▪ *Evaluating*
5th and 6th classes	▪ *Questioning* ▪ *Observing* ▪ *Predicting* ▪ *Investigating and experimenting* ▪ *Estimating and measuring* ▪ *Analysing* *Sorting and classifying* *Recognising patterns* *Interpreting* ▪ *Recording and communicating* ▪ *Evaluating*	▪ *Exploring* ▪ *Planning* ▪ *Making* ▪ *Evaluating*

[10] Science in Primary Schools, Phase 1 Final Report