Draft background paper and brief for the review of leaving certificate physics, chemistry and biology

NCCA
An Chomhairle Náisiúnta Curaclaim agus Measúnachta
National Council for Curriculum and Assessment

Contents

1. Introduction

New specifications for Leaving Certificate physics, chemistry and biology are scheduled to be introduced in 2021. The curriculum specification for each subject will be published a year earlier in September 2020. This paper provides a background for the development of the curriculum specifications and forms the basis of a consultation which will seek to elicit the views of a range of interested parties including practicing teachers and students to contribute to the development of the new subject specifications for these subjects.

This paper sets out the context to the request from the Department of Education and Skills (DES) to the National Council for Curriculum and Assessment (NCCA) to review the draft specifications for Leaving Certificate physics, biology and chemistry in light of the time that has passed since their development and agreement by Council in March 2014. The DES also requested NCCA to examine the feasibility of integrating a coursework assessment component, similar to that applying to other subjects. The implications of various national initiatives, which have occurred in the interim, and some of the potential challenges facing the development of the specifications are explored. The paper addresses themes such as curricular coherence, and the purpose of science education. Opportunities and challenges in assessment both nationally and internationally are discussed. Following a conclusion to the paper, Annexe 1 outlines the common template for the design of the specification and Annexe 2 sets out a proposed brief for the development of the specifications.

The work of the development groups, which will commence in autumn 2019, will be guided by the brief for the review.

2. Background

The current Leaving Certificate physics and chemistry syllabi were first taught in 2000. Two years later the current Leaving Certificate biology syllabus was introduced. Since this time, almost twenty years ago, significant curriculum and assessment developments have taken place. This chapter sets out the developments which occurred and outlines the policy initiatives introduced over the last decade which are most relevant to the revision of specifications for Leaving Certificate physics, chemistry, and biology.

2.1 Development of draft specifications

In September 2006, the NCCA commenced the development of a new set of specifications that would meet the needs of twenty-first century learners and that would also be more likely to prepare them for post-school pathways. Whilst there was universal agreement that scientific literacy is a necessary literacy for twenty-first century citizenship there had also been much research conducted into student preparedness for post-school courses (Marchall, Summers, Woolnough, 1999; Conley, 2003). One of the most dominant themes raised by participants in these studies is the importance of the habits of mind students develop in post-primary school and bring with them to post-school courses.

> *The habits of mind include critical thinking, analytic thinking and problem solving; an inquisitive nature and interest in taking advantage of what a research university has to offer; the willingness to accept critical feedback and to adjust based on such feedback; openness to possible failures from time to time; and the ability and desire to cope with frustrating and ambiguous learning tasks. Other critical skills include the ability to express one's self in writing and orally in a clear and convincing fashion; to discern the relative importance and credibility of various sources of information; to draw inferences and reach conclusions independently; and to use technology as a tool to assist the learning process rather than as a crutch.*
>
> (Conley, 2003, p. 8)

During the period of the development of the new specifications, the senior cycle vision of creative, confident and actively involved young people was forming, deeply influenced by the studies into habits of mind. *Towards Learning* (NCCA 2009) set out that vision, the values on which it is based and the principles that shape the review and development of senior cycle curriculum and assessment. The revised specifications thus placed the learner as the focus of the educational experience, enabling them to become resourceful and confident, to participate actively in society, to build an interest in learning and the ability to learn throughout their lives. By embedding the five keys skills of senior cycle education — critical and creative thinking, communicating, information processing, being personally effective and working with others — in the learning outcomes of each subject, learners were to be assisted in reaching their full potential, both during their time in school and in the future. In an effort to more closely align the different elements of the specification, a new practical assessment component was proposed, to be externally assessed and allocated 20% of the final marks. The final written exam would be allocated 80% of the final marks. The draft specification was approved for consultation in 2012 and a report on the consultation was published (NCCA, 2012). Following the consultation process a number of adjustments were made to the draft specifications:

- all three specifications became more uniform, adhering more closely to common layouts
- the weighting for the practical assessment component was increased to 30%.

The consultation also noted the concern expressed around the nature and scale of support documentation that would need to be made available with the specifications. In March 2014, the three specifications for biology, physics and chemistry were approved by Council pending the findings from a trialling of the practical assessments to gather information on how and whether such an examination component might work.

2.2 Trialling of Practical Assessments

In September 2016, a proposal for trialling the practical assessment, submitted by the SEC was approved by the Department of Education and Skills (SEC, 2018, p.8). Trialling in schools began in October 2017. The areas to be considered in the trialling included deployment and delivery, the validity of potential assessment tasks and logistics such as the role of the science teacher in supporting any arrangements and the number of students that could be accommodated in any given session.
Although the SEC concluded that it could broadly assess the skills identified in the curriculum specifications, there was a heavily weighted caveat accompanying this conclusion:

> *a view emerged from early on in the project that the tasks were not adequately addressing the full range of skills that are important when engaging in practical experimental work in science and which are emphasised in modern science curricula. In particular, there was much discussion as to the degree to which the candidates should be required to apply their practical and investigative skills to less familiar 'unseen' scenarios and contexts.*
>
> *(SEC, 2018, p.109)*

The trialling also identified challenges to the security and integrity of the practical assessment component, noting that:

- it would be physically impossible to host simultaneous assessments of the students
- students who sit the exam later than others may gain an advantage.

Although the report offers several scenarios to address this issue of fairness (SEC, 2018, pp.111 – 113), it was concluded it would remain challenging to fairly assess the investigative skills of students in unfamiliar contexts. Given the systemic implications and far-reaching consequences of any decision to roll out a practical assessment as a component of the Leaving Certificate examination in the science subjects, it was proposed that the trialling project would benefit from being reviewed by an independent external agent, in order to provide assurance to stakeholders that the trialling project was fairly and appropriately planned and executed. Professor John Holman, Emeritus Professor of Chemistry at the University of York and President of the Royal Society of Chemistry (2016-2018), conducted this review. His report (SEC, 2018, pp.130 – 136), which was completed and submitted to the DES in 2018, praised the quality of the planning, execution and report writing. Notwithstanding the quality of the trial, Professor Holman drew attention to a number of serious concerns:

- the proposed number of 12 students per session was deemed too onerous upon an examiner
- the implication of a reduction in the number of students per session would be an increased number of sessions or an increased number of examiners
- equity and fairness might be compromised as the facilities in schools across the system might not be fit for the purpose of the practical assessment.

In January 2019, following consideration of the report and its advice, the DES decided not to implement the practical assessment and requested the NCCA to:

- review the three Leaving Certificate science specifications in light of the time that has passed since their development and agreement by Council, including the introduction in the meantime of the new science curriculum as part of the *Framework for Junior Cycle*
- examine the feasibility of integrating a coursework assessment component, similar to that currently applying to other subjects, into each of the three subject specifications. This component should facilitate an alternative assessment approach, which should allow for the assessment of inquiry-based learning, critical thinking and elements of experimental investigation (practical work).

2.3 SEC Chief Examiners' Reports

The SEC Chief Examiners' Reports provide a review of the performance of candidates in the examinations and detailed analysis of the standards of student response. The reports are published in a selected number of subjects each year. There is strong evidence from the most recently published SEC Chief Examiner Reports (2013) on the Leaving Certificate physics, biology and chemistry examinations, that students' strengths lie in their ability to display evidence of the acquisition of propositional knowledge (knowing that).

> *Candidates showed strength in answering standard questions on definitions and statements of physical principles and laws.*
>
> *(SEC, 2013a, p.18)*

However, students are challenged when asked to display evidence of procedural knowledge (knowing how) and epistemic knowledge (knowing about)

> *Candidates appeared to have difficulty applying knowledge of physical principles and laws to practical contexts, whether familiar or unfamiliar.*
>
> *(SEC, 2013a, p.18)*

These reports concluded that:

- In general, the overall performance and standard of answering of students in the 2013 examinations was similar to previous years
- Students demonstrated strengths in knowledge and recall of facts and statements of laws and principles
- Most students, especially at higher level, answered extra questions, showing wide knowledge and coverage of the syllabi
- While there was strength in these areas, students tended to show weaknesses in applying their knowledge and expressing their understanding of concepts.

Given these conclusions, the Chief Examiner's Report on Physics, recommends that:

> *Students should be encouraged to approach the subject of physics not as a body of disparate pieces of information to be memorised, but rather as a series of interdependent and mutually reinforcing principles to be understood so that they may be applied to a wide variety of contexts.*
>
> *(SEC, 2013a, p.19)*

2.4 Junior Cycle Science (2015)

In the two decades since the design of the current Leaving Certificate science subjects, the science curriculum for junior cycle has changed twice; in 2003, and again in 2015 as part of junior cycle reform. The *Framework for Junior Cycle* (DES, 2015a) describes the key educational changes established by the DES for the first three years in post-primary schools.

- Schools can introduce combinations of subjects and short courses, alongside programmes of wellbeing and other learning experiences
- A varied approach to assessment reduces the focus on a single terminal examination at the end of the third year
- A greater emphasis is placed on classroom-based assessment (CBA) and formative assessment.

Students of Junior Cycle Science completed their second CBA in March 2019 and sat the final written examination of the new specification for the first time in June 2019. The Junior Cycle Science specification (NCCA/DES, 2015) aims to:

> *develop students' evidence-based understanding of the natural world and their ability to gather and evaluate evidence: to consolidate and deepen their skills of working scientifically; to make them more self-aware as learners and become competent and confident in their ability to use and apply science in their everyday lives.*
>
> *(NCCA/DES, 2015)*

There is a strong focus on developing scientifically literate students with an understanding of the natural world. It defines scientific literacy as *the ability to engage with science-related issues, and with the ideas of science, as a reflective citizen* (NCCA/DES, 2015, p.9). The specification is composed of five strands. To embed scientific inquiry throughout the specification, Strand 1, *The Nature of Science*, is a unifying strand with a strong focus on how science works. The concepts of this unifying strand permeate all other strands which are built on the same four essential elements of building blocks, systems and interactions, energy and sustainability. The core scientific ideas presented in the contextual strands then provide a context for students to continually build on and revise their scientific knowledge and skills as they progress in their learning.

The specification is designed to allow *the teachers to employ a variety of teaching strategies depending on the targeted learning outcomes, the needs of their students, and their personal preferences*. (NCCA/DES, 2015) A continuum of inquiry is offered as a method by which students can be given opportunities by the teacher to progress their scientific inquiry skills. The categories on the continuum are limited inquiry (implying greater teacher instruction), structured inquiry, guided inquiry and open inquiry (implying limited or no guidance from the teacher). The specification also encourages the teachers to *provide opportunities for students to investigate contemporary scientific issues, supporting students to make connections between science, other subjects and everyday experiences (ibid).* Students must complete two CBAs during the three years of studying Junior Cycle Science. The first CBA is an Extended Experimental Investigation and the second is a Science in Society Investigation. Students complete an Assessment Task directly related to their second CBA, and sit a final examination at the end of third year. The implications of the specification for progression from junior cycle and for assessment at senior cycle will be explored in chapter 5.

2.5 Recently developed senior cycle specifications

There have been six senior cycle specifications designed to a common template and approved by Council in the period from 2016 to 2019. The six specifications are for the subjects Politics and Society, Physical Education, Computer Science, Economics, Agricultural Science and Applied Mathematics. Designed for 180 hours of class contact time, they are organised into strands with learning set out in the form of learning outcomes whose assessment includes a final written examination and at least one coursework component worth at least 20% of the final marks.

The specification of greatest relevance to the development of specifications for the senior cycle science subjects is the Leaving Certificate Agricultural Science specification. Following an initial consultation on a background paper in late 2014 and a Consultation Report in March 2015, a revised specification for Leaving Certificate Agricultural Science was developed and approved by the NCCA in 2016. This new specification, which will be introduced in schools in September 2019, offers continuity and progression from Junior Cycle Science by:

- developing student understanding of the purposes and principles underpinning the practice of science, in addition to the ability to understand and rigorously apply the concepts, laws and theories of science
- embedding literacy and numeracy as well as the five key skills of senior cycle education in the learning outcomes across each of the four strands
- providing for a coursework component for learners to display evidence of learning not easily assessed by written examination.

2.6 STEM Education Policy 2017 – 2026

Of the system-wide education strategies launched and implemented since 2014, the most relevant and immediate for the development of senior cycle science subjects is the STEM Education Policy Statement (DES, 2017).

> *The NCCA will design subject specifications having regard to this Policy Statement, while the State Examinations Commission will support models of assessment to complement its objectives.*
>
> *(DES, 2017, p. 20)*

This policy statement acknowledges the many strengths in STEM education in Ireland and identifies a number of challenges which resonate with the task of reviewing the specifications for Leaving Certificate sciences, in particular the need to:

- *Ensure that Irish students' learning in STEM disciplines significantly improves, including the further development of skills such as problem-solving, inquiry-based learning and team working to address demands from the world of work*
- *Increase the number of students choosing STEM subjects in post-primary schools, those progressing to STEM pathways in Further or Higher Education and those who take up careers in STEM*
- *Increase participation of females in STEM education and careers*
- *Raise interest in, and awareness of the range of exciting careers in STEM*
- *Ensure young people sustain their involvement in STEM education.*

(DES, 2017, p. 10)

The policy identifies three key principles that will underpin all STEM education initiatives.

- *STEM is about igniting learners' curiosity so they participate in solving real world problems and make informed career choices.*
- *STEM is interdisciplinary, enabling learners to build and apply knowledge, deepen their understanding and develop creative and critical thinking skills within authentic contexts.*
- *STEM education embodies creativity, art and design.*

(DES, 2017, p. 9)

These principles are intended to connect practices to purpose and are underpinned by an acknowledgment of how vital scientific literacy is to students living in a world increasingly shaped by science and technology. The development of the science subjects will need to consider how to nurture a diverse range of students; those who wish to progress to STEM careers through third level or technical apprenticeships, as well as those who will pursue opportunities outside STEM. In a broader sense, the principles are also intended to guide the Department, schools, leaders, teachers and key stakeholders to play a proactive role in providing a high-quality STEM experience for our young people.

2.7 The Digital Strategy for Schools

The *Digital Strategy for Schools 2015 - 2020: Enhancing Teaching, Learning and Assessment* is underpinned by five principles (DES, 2015b, p. 9) which have particular relevance for the development of revised specifications in science. These principles seek to embed digital technology in the school system and in particular to provide enhanced and meaningful learning opportunities for students through a *constructivist pedagogical orientation* in the classroom. One of the aims of the digital strategy is technology-enhanced learning opportunities. Rather than technology being used solely as a replacement for older forms of data presentation, such as books or whiteboards, the strategy seeks to embed technology in such a way that the pedagogical contract between the teacher and the student is transformed. Ultimately it involves the transition in education from teachers and students being solely consumers of technology to being consumers and creators. This is one of the most significant challenges ahead. The final evaluation report of the Digital Learning Framework Trial, a key element of the Digital Strategy, suggests that this challenge is in the process of being addressed. For the vast majority of teachers surveyed, there was a moderate or significant increase in collaboration with colleagues coupled with enhanced engagement and interest from students. (ERC, 2018, p. 121).

2.8 Senior cycle review

The NCCA commenced a review of senior cycle education in late 2016. At the point of drafting this background paper, the review has entered a phase of public consultation on the emerging ideas to date. All current information related to the review can be found at www.ncca.ie/en/senior-cycle/senior-cycle-review.

Whilst all aspects of the review will have an impact on the future development of senior cycle subjects, it is clear, from those consulted to date, that there is a general consensus that senior cycle education should promote lifelong learning, participation, relevance, enjoyment, creativity and innovation. The collective vision emerging is that the experience of senior cycle education should be one that:

- links within and across learning areas
- challenges students appropriately
- connects with the lives of students and the wider world
- empowers all students to learn
- encourages students to own their own learning.

2.9 Timeline from 2000 - 2019

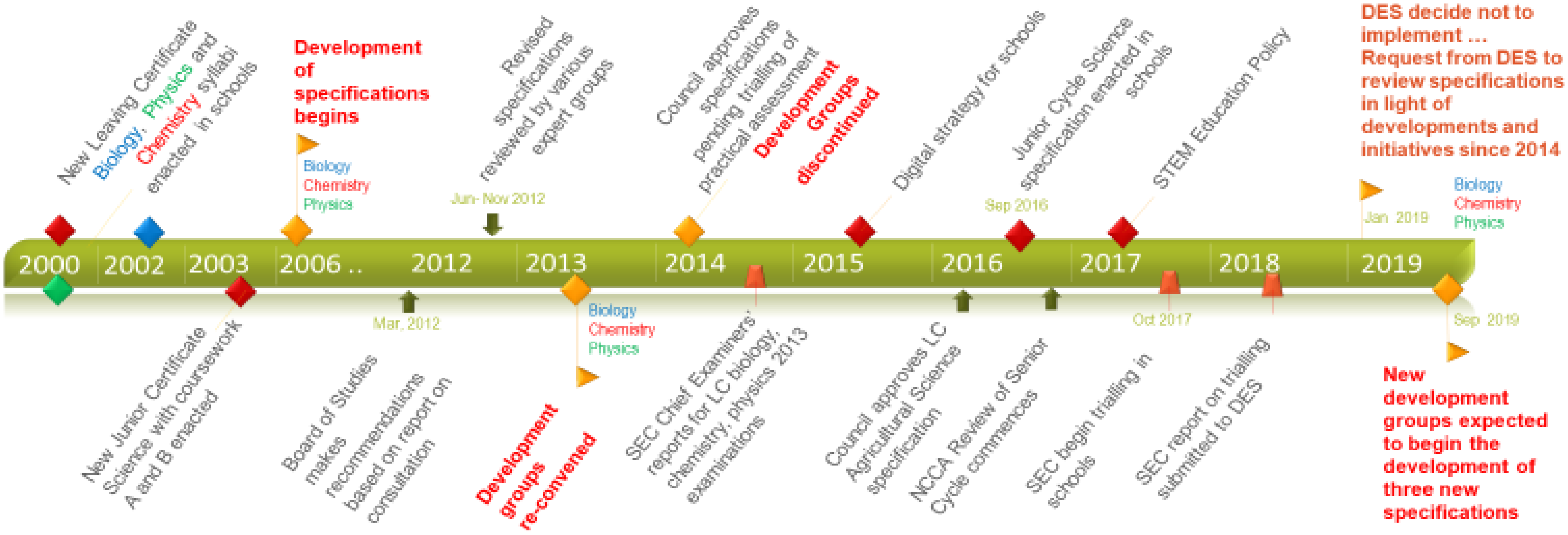

Figure 1: Timeline of key initiative and policies 2000 - 2019.

Chapter 2: summary

The current syllabi for Leaving Certificate physics, chemistry, and biology are almost twenty years old. Since their introduction, significant curriculum and assessment developments have occurred. In junior cycle, the science curriculum changed twice - in 2003 and 2015. The most fundamental changes occurred recently as part of the reform of junior cycle. Some of the most relevant and significant features have been the introduction of two Classroom-Based Assessments and the inclusion of *The Nature of Science* as a unifying strand in the specification, which has placed the nature of science and its processes of inquiry at the core rather than the margins of science education.

In senior cycle, significant progress was made in developing draft specifications for biology, chemistry and physics. They were approved by Council in March 2014, pending the outcome of the trialling of the practical assessment component. In 2018 the SEC submitted its report on the trial. Following its consideration of the report the DES decided against implementation and requested the NCCA to revise the specifications in light of the time that had passed since their conditional approval by Council.

Some of the policy initiatives introduced over the last decade which are most relevant to the revision of the draft specifications include:

- The STEM Education policy 2017 - 2026: which describes how science education, two decades into 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 science and technology.
- The Digital Strategy for schools 2015 - 2020: which has improved the fundamental digital literacy of students and teachers. It presents future curriculum development groups with opportunities to provide contexts for students to utilise their skills as both consumers and creators of digital artefacts.
- The introduction of new and revised senior cycle subject specifications: which offer continuity and progression from the *Framework for Junior Cycle*, in particular, Leaving Certificate Agricultural Science. It has placed the scientific process at the core, embedded senior cycle key skills in the learning outcomes and incorporated a coursework component into the assessment components.

The work of the development groups needs to be cognisant of these policy developments and of the ongoing review of senior cycle.

3. Evolution of science education – opportunities and challenges

The development of science education has been influenced by many factors throughout its history. Each reform has brought its own benefits and challenges. For example, the current Leaving Certificate syllabi for physics, chemistry and biology were developed against a backdrop of declining participation in these subjects. This chapter sets out some of the current challenges and issues facing the revision of specifications for senior cycle science.

3.1 A brief history of science education

In the 19th century, studying science was considered by many in society as unworthy of the educated classes (DeBoer, 1991). Prominent scientists of the time, from Faraday to Tyndall, campaigned for the introduction of science as an essential skill that was increasingly relevant to a modern technological society. They argued students would develop critical thinking skills by observing the natural world and carrying out independent inquiry-based experiments (DeBoer, 2000). In the early decades of the 20th century, John Dewey's views epitomised the growing need for scientific literacy:

> *Contemporary civilization rests so largely upon applied science that no one can really understand it who does not grasp something of the scientific methods and results that underlie it.*
>
> *(Dewey, 1909)*

However, by the 1930s the pendulum of curriculum development had swung away from relevance to everyday life towards the fundamental principles of science. World War II and the subsequent Cold War focussed the attention of countries on the strategic value of scientific knowledge in pursuing national imperatives. The impact of the Soviet Union's Sputnik 1, the first satellite launched in space, on the American educational system was revolutionary. The US government invested heavily in science education with the goal to produce *a bumper crop of young adults in STEM careers rather than to improve science education* (Anelli, 2011). As the decades passed, the attention to science never waned but the *reasons for anxiety about the quality of science education expanded* (Atkin et al. 2003). Increasing investment in quality science education was viewed as having the potential to improve the economy and serve the wider interests of countries. Thus, a disconnect emerged between the science curriculum and the everyday lives of students.

In the 1970s a new wave of scientific thinking, Science Technology and Society (STS), sought to reconnect the science curriculum to students' lives, believing it to be a pedagogical imperative. They argued that science should be taught to meet the personal needs of students in the context of contemporary societal issues. Orpwood (2001) has demonstrated that, by the 1980s and into the 1990s, the integration of STS focussed the curriculum less on scientific content knowledge and more on the complex relationships between science, technology, society and the environment. With the focus on both scientific content and STS, the *science as an essential skills* argument put forward by Faraday and Tyndall was remoulded for the late 20th century. The report *Science Education Now* (EC, 2007, p. 9) points to the existence of two historically contrasting approaches in science education: the deductive and the inductive approach. The deductive approach is the more traditional approach associated with the teacher explaining concepts and students applying this new knowledge. The inductive approach is oriented towards observation and experimentation. By the end of the 20th Century, the inductive approach had grown in prominence and become known as inquiry-based learning (IBL). Inquiry-based learning is based on the investigation of questions, scenarios or problems. The level of inquiry can range from limited inquiry, requiring high levels of teacher guidance, to open inquiry or learning by discovery. Inquirers identify and research issues and questions to develop their knowledge or solutions.

Contemporaneously in the US, concern over declining performances in TIMSS and a need to compete in a global market prompted a movement known as the standard reform. The first US national education standard (NRC, 1996) balanced scientific literacy against academic oriented science by stating that *to keep pace in global markets, the United States needs to have an equally capable citizenry* (NRC, 1996, p. 2). Both the STS and standard reform movements had a significant influence on the development of science curricula relevant to the everyday lives of students.

3.2 Early 21st century responses in Ireland

A similar narrative was influencing the development of science curricula in Ireland at this time. Development of the current senior cycle syllabi began in the mid-1990s, against a backdrop of declining participation in these subjects (Byrne, 1998). The Physics and Chemistry syllabi were first taught in 2000 and assessed in 2002, and the Biology syllabus was first taught and assessed in 2002 and 2004 respectively.

In October 2000, as the current senior cycle syllabi were being implemented, and following years of concern around the declining uptake of science subjects at second and third level, the DES set up a Task Force on the Physical Sciences to:

> *address concerns about the declining levels of participation in the physical sciences at second level and in higher education and in recognition of the fact that the development of the skills base in the area of the physical sciences is central to sustaining Ireland's economic growth.*
>
> *(DES, 2002)*

The report of this group, published in 2002, recommended a six-point action plan strategy. It suggested action in areas such as equity and access (including gender equity), the promotion of science and careers and changes to teaching and learning (DES, 2002, p.114). Embracing the spirit of these recommendations and following the design of the current Leaving Certificate science subjects, a new Junior Cycle Science syllabus was introduced in 2003. This syllabus was generally seen as a positive development in science education in Ireland with its aim to foster an inquiry-based approach to teaching and learning and move the focus away from the terminal examination by including a second assessment component (NCCA, 2013).

3.3 Emerging challenges

As jurisdictions implemented these curricular changes in the first decade of the early 21st century, Osborne and Dillon (2008) drew attention to the gap between the intended and the enacted curricula that began to emerge. While there have been many explanations offered for this, the most common has been that changes to assessment did not align sufficiently with changes to the curriculum. As the next chapter will discuss, the challenge for this review will be alignment across the whole education system, from the design of learning outcomes to the specification of appropriate pedagogy and assessment. Research suggests that coherence across an education system stems from clear purpose and a shared vision (Sullanmaa et al., 2019; Fortus et al., 2015; Allen & Penuel, 2015; Schmidt & Prawat, 2006). In his review of the draft Leaving Certificate science specifications from 2012, Professor Per Kind of Durham University alluded to this notion when he noted that *the documents, however, do not explain what exactly the purpose of the courses is beyond developing the learner*.

In addition to the broad considerations of alignment and coherence which face all curriculum developers, it remains a constant challenge for policy makers to design a modern science curriculum that will develop scientifically literate citizens as well as meet the needs of those who wish to pursue a science-related career. A modern specification should be relevant to the global challenges facing society – sustainable energy sources, providing sufficient food and water, climate change and diminishing ecological diversity. Scientific innovations are increasingly rooted in the need to find solutions to these challenges that face students now and in the future. But these challenges will require not only innovative solutions from the science community, but also global social, political and economic ones that are informed by a broad-based knowledge of the science that underpins the challenges (NRC, 2012). Accommodating the needs of such a diverse range of learners, coupled with a need for a broader base of scientifically literate students, brings its own pedagogical complexities and challenges. Within this context the tensions between distinct pedagogical approaches, including inductive and deductive based learning methodologies, have often pushed the discussions into polarised views of the learning process in the classroom. Research in this area is discussed in the next section.

As highlighted in the SEC Chief Examiners' Reports (SEC, 2013), senior cycle science students show evidence of strong knowledge of facts, laws and principles but demonstrate wide variations in levels of application and understanding of this knowledge. In other words, students currently demonstrate strong propositional knowledge with wide variations in procedural and epistemic knowledge. One of the fundamental challenges in this area for review will be to design a balanced specification that underpins propositional knowledge and supports the acquisition of procedural and epistemic knowledge.

3.4 Some current research and perspectives

Recent studies (Teig et al (2018), Jerrim et al (2019) and Scott et al (2018)) suggest that overuse of any one method of teaching or learning can have a negative effect on student achievement and also means a de facto abandonment of a blended pedagogical approach to learning science. Using an extensive dataset from Norwegian TIMSS 2015 studies, Teig, Scherer and Nilsen (2018) set out to examine the relationship between IBL and student achievement in science. Previous studies had assumed a linear relationship. Their studies confirmed this relationship, but only within a range of frequency of use of IBL in the classroom. Teig et al's study concluded that there was in fact a curvilinear relationship between IBL and student achievement in science. Essentially, they found a law of diminishing returns if IBL was over-used.

> *The increasing use of inquiry-based teaching was correlated with higher achievement in science until it reached an optimum value, then this association decreased as the use of the strategy increased. Furthermore, when there was a very high frequency of inquiry activities, the relationship between inquiry and achievement became negative. This nonlinear pattern indicates that excessive use of inquiry strategy in science classrooms may have diminishing returns for increasing student achievement because the frequency of student investigations per se does not lead to better performance.* (Teig et al, 2018)

Scott et al (2018) examined the literature around the efficacy of IBL. They found the dichotomy between the conceptual frameworks of IBL, whether it was guided or a completely open form, and a more didactic approach, including direct instruction, was unhelpful in creating an informed discussion.

> *These conceptual frameworks, contrary to what critics of inquiry have claimed, do not stand in opposition to key elements of traditional forms of education, such as direct instruction. Rather, they seek to introduce authentic assessment practices, increase the quality of student assignments and moreover, extend the range of instructional supports employed in the classroom. Research in the learning sciences has shown that teaching and learning sequences that possess such characteristics support deeper understanding and more intellectually engaging learning experiences for students.*
>
> *(Tieg et al., 2018)*

The OECD report on PISA 2015 went on to make similar recommendations for practice and policy, noting that:

> *For instance, in almost all education systems, students score higher in science when they reported that their science teachers "explain scientific ideas", "discuss their questions" or "demonstrate an idea" more frequently. They also score higher in science in almost all school systems when they reported that their science teachers "adapt the lesson to their needs and knowledge" or "provide individual help when a student has difficulties understanding a topic or task". Interestingly, students are more likely to expect to pursue a career in a science-related occupation when they perceive that their science teachers use a greater diversity of teaching strategies, regardless of which they are.*
>
> *(OECD, 2016, pp. 228)*

Jerrim, Oliver and Simms (2019) examined data from 5194 pupils in England who were involved in the 2015 PISA studies, when science was the subject in focus.

> *Our interpretation of these results is therefore that the benefit of allowing pupils to acquire their own knowledge through investigation are small and, consistent with the theory reviewed in the introduction, can easily be cancelled out by the additional cognitive load involved in conducting such investigations. This research has implications for the practice of science teaching. In particular, it suggests that science teachers should not overuse inquiry methods.*
>
> (Jerrim et al., 2019)

They acknowledge that their analysis does not capture the scientific inquiry skills nor the investigative skills associated with IBL forms of learning. Kirschner et al. (2006) popularised the cognitive load theory to suggest that IBL, in its various guises, produces a *heavy working memory load that is detrimental to learning*, and that teaching strategies that do not complement how humans learn are not likely to be effective. Their study concludes:

> *In so far as there is any evidence from controlled studies, it almost uniformly supports direct, strong instructional guidance rather than constructivist-based*

> *minimal guidance during the instruction of novice to intermediate learners.*
> *(Kirschner et al., 2006)*

Hmelo-Silver et al. (2007) raised some concerns regarding the manner in which Kirschner and his colleagues conflated any pedagogical idea that wasn't didactic under the single moniker of IBL. They

> *indiscriminately lumped together several distinct pedagogical approaches—constructivist, discovery, problem-based, experiential, and inquiry-based—under the category of minimally guided instruction.*
> *(Hmelo-Silver, 2007, p. 99)*

Furthermore, in their recent analysis of literature around these learning concepts, Scott et al. (2019) showed that *criticisms of inquiry-based approaches to education are largely directed at discovery learning, which has limited educational value.*

These ideas around different approaches to learning, and therefore teaching, are ultimately about the most effective methods of teaching and learning in the classroom. As mentioned earlier the challenge for this review is to decide what knowledge is worth learning by students and how to specify a balance in that knowledge between propositional knowledge (knowing that) and procedural and epistemic knowledge (knowing how and knowing about) at an appropriate level for students at this stage in their development.

Chapter 3: summary

Historically, changing socio-political contexts have influenced and moulded science education. The current challenges faced by society need solutions not only from the science community, but also from the wide base of a scientifically literate citizenry, thus shifting the focus of science education. Learning to understand and rigorously apply the concepts, laws and theories of science remain as an undisputed central tenet of a quality science education.

However, there is an increasing focus on the importance of learning about the process by which this knowledge is established – how science works. This has led to some debate about the importance of one type of knowledge over another. Much of the debate manifests itself in contestation about the effectiveness of different approaches to teaching and learning in contributing to student achievement in science. It could be argued that this tension and polarisation of perspectives has given rise to false dichotomies. For example, recent studies suggest that overuse of any one method of teaching or learning can have a negative effect on student achievement. Evidence also suggests that greater diversity of teaching and learning strategies is correlated with higher achievement among students and greater likelihood of their pursuing a science-related career.

For science educators and curriculum developers in general, the difficulty has been to achieve and facilitate an interconnected and coherent curriculum, aligned to a clear, common purpose. This includes all aspects of the curriculum, including learning outcomes, pedagogy and assessment.

4. Specifying knowledge in a coherent curriculum

Curricular coherence is the alignment of all aspects of the curriculum, from the design of learning outcomes to the specification of assessment, with a clear purpose and a shared vision. This chapter explores the theme of curricular coherence in the context of developing new curriculum specifications in science subjects. The findings of commissioned research on the experiences of international jurisdictions who have moved to a learning outcomes-based curriculum are explored with a particular focus on the curricular and pedagogical implications of these findings.

4.1 Curricular coherence

Schmidt and Prawat suggest that there are two dimensions to curriculum coherence:

- *all elements of education arrangements are aligned in respect of purpose and impact*
- *no incentives or drivers create significant role conflict for professionals and others located in those arrangements.*

(Schmidt & Prawat, 2006)

Lessons learned from similar research has been that changes in curriculum need to be closely aligned and coherent with changes in policy and broad, system arrangements (Fortus et al., 2015; Allen & Penuel, 2015; Schmidt & Prawat, 2006). This implies that not only should there be alignment horizontally within the specification of learning outcomes, assessment, content, key skills, and so forth but that this alignment needs to extend right across the education system to pedagogy, inspections, continued professional development and initial teacher education.

Sullanmaa et al. (2019), in their analysis of perceived coherence in the Finnish system, found that clear direction and purpose was a vital component of a coherent curriculum.

> *It has been proposed that providing a consistent foundation for constructing a shared vision of the curriculum's goals and aligning activities among the different stakeholders within the school and educational system is important in successful curriculum reform.*
>
> *(Sullanmaa, J. et al., 2019)*

Research, which will be explored in greater detail later, seems to suggest that a shared vision of the purpose and direction of the curriculum is vital as a foundation for building coherence (Sullanmaa et al., 2019; Manyukhina & Wyse, 2019) and as previously stated, alignment of each aspect of the curriculum to the objectives is vital for maintaining curriculum coherence. Misalignment of key aspects of a curriculum can result in fragmentation. This means that different aspects of the curriculum will be working to different purposes, and gaps consequently emerge between the intended and the enacted curriculum. Maintaining curricular coherence, therefore requires an iterative process of communication and reflection among all stakeholders throughout the enactment of the specification. Professor Áine Hyland (ISTA, 2014) draws attention to the need for greater alignment in any revised specifications. Her report for the Irish Science Teachers' Association (ISTA) annual conference acknowledges that the current syllabi, although highly regarded by teachers, are in need of reform. She points to the lack of alignment as the limiting factor in the effectiveness of the teaching, learning and assessment of students in achieving the objectives and meeting the purpose of the specification:

> *the problem of rote-learning and memorisation lies in the type of assessment we have in Ireland – 100% written terminal examination; and inadequate congruence and alignment between the desired learning outcomes of syllabi, the approach to teaching and learning and the modes and techniques of assessment.*
> *(Hyland, 2014)*

Assessment within the context of a coherent curriculum will be explored in more detail in the next chapter.

4.2 Learning outcomes: international case studies

Using learning outcomes in the development of new curricula, has placed emphasis on the knowledge, skills, values and attitudes students will learn, as well as focusing on the subject matter of the course or syllabus. They also play a significant role in ensuring that the aims of education, the objectives of the relevant curriculum component, the learning/teaching strategies adopted, and the assessment used are consistent with each other. In other words, their purpose is to contribute to ensuring that the various elements of the curriculum are aligned with each other.

Since the early 2000s, there has been a move in Ireland towards an outcomes-based approach to curriculum development, with learning being defined in terms of what students should be able to know and do at the end of a course. Learning outcomes were first used in the rebalanced Junior Certificate subject syllabuses in the early 2000s. Since then, they have been a key feature of junior cycle, senior cycle and primary curriculum developments. In 2011, The National Strategy for Literacy and Numeracy called for curriculum statements at all stages of schooling to adopt a 'Learning Outcomes' design, in which the expected learning outcomes to be achieved are clearly stated:

> *A "Learning Outcomes" approach needs to be incorporated into all curriculum statements at primary level and in all new syllabuses at post-primary levels as they come on stream. Curricula should state clearly the skills and competences expected of learners at six points in their development (end of early years/infants, end of second class, end of fourth class, end of primary stage, end of junior cycle and end of senior cycle).* *(DES, 2011)*

Some stakeholders expressed concerns about the enactment of the specifications following the consultation on the draft specifications (NCCA, 2012; Hyland, 2014). This reinforces evidence internationally that moving to curricula based on learning outcomes is not without significant cultural and pedagogical complexities. To inform this review and to learn from other jurisdictions whose curricular policy has also shifted away from prescriptive specification of content towards a more generic, skill-based approach articulated as learning outcomes, the NCCA commissioned *Learning Outcomes: An International Perspective (NCCA, 2019).* This case-study of five jurisdictions, which was prepared by Professor Mark Priestley and peer reviewed before publication, acknowledges that there is widespread support within transnational policy circles for this shift in policy. It highlights the cultural and pedagogical complexities associated with implementing this scale of change within education systems such as Ireland's, where teachers have been accustomed to having content specified, and where there are long-established conventions of mainstream schooling that reward the acquisition of disciplinary, propositional knowledge and student performance in external examinations.

The case study warns about how the failure to address the question of what knowledge is of most worth can result in curricular fragmentation. In this context an important question to address will be: What knowledge does an educated young person need to acquire in order to become a scientifically literate, critically engaged and effective member of a complex modern democratic society or to progress to a career in STEM? The question is further complicated in the high-stakes testing environment of the Leaving Certificate where evidence from research into the back-wash effect of high-stakes testing, such as Koretz et al (2008), has shown that the knowledge that is valued in the classroom is that which appears on tests. This issue will be further explored in the chapter on assessment.

4.3 Implications of the learning outcomes case studies

Epistemology is the study of knowledge; the nature of knowledge is complex and epistemologists have identified those very different forms of knowledge mentioned earlier in this paper. Although these different forms of knowledge are most commonly referred to in practice as knowledge and skills they have been defined in literature as propositional knowledge (knowing that), procedural knowledge (knowing how) and epistemic knowledge (knowing about).

The international case studies (NCCA, 2019) note that when learning outcomes are used to specify knowledge in curricular documents, teachers are expected to incorporate pedagogical approaches that support students going beyond simply acquiring propositional knowledge of facts. This is to enable students to develop deeper understandings, to make connections between different knowledge domains, and to be able to apply knowledge. To achieve this, the case studies found that teachers not only have to increase their Pedagogical Content Knowledge (PCK), but in many cases disciplinary knowledge as well, in order to engage students in developing deep understanding and powerful knowledge (Biesta, 2014). Part of the process involves teacher sense-making in relation to new policy, something that successful systems like Finland have largely achieved in relation to their curriculum reforms (Pyhältö et al., 2018). Such processes enable teachers to construct meaning in relation to new curricular concepts, and to differentiate between new and existing practices; importantly, they enable teachers to enhance their theories of knowledge and practice, in turn providing the potential for more expansive engagement with new curricula.

Many international research studies have attempted to generate and realise such science curricula that go beyond the acquisition of facts and into a knowledge domain that allows for a deeper, more interconnected understanding of the key ideas all future citizens should encounter in their science education. In 2014, under the auspices of the Inter-Academy Partnership, a global network of international science academies, international science education experts convened to specify the knowledge and ideas students should encounter in their science education from primary through to upper secondary. They produced a document entitled Working with Big Ideas in Science (Harlen, 2015), which was partially in response to what they perceived as an *overcrowded and fragmented curriculum*. Their solution was:

> *to conceive the goals of science education, not in terms of the knowledge of a body of facts and theories, but as a progression towards understanding key ideas of relevance to students' lives during and beyond their school years*
>
> *(Harlen, 2015)*

They conceived 10 ideas *of* science and 4 ideas *about* science. Their 4 ideas about science constitute a rounded definition of the nature of science, its applications and implications.

- *Science is about finding the cause or causes of phenomena in the natural world*
- *Scientific explanations, theories and models are those that best fit the evidence available at a particular time*
- *The knowledge produced by science is used in engineering and technologies to create products to serve human ends*
- *Applications of science often have ethical, social, economic and political implications*

(Harlen, 2015)

The importance of PCK is also highlighted in the learning outcomes case studies, in particular the ability to link facts to concepts and the role that progression plays in developing curricular coherence. Millar

(2016), in his evaluation of the *York Science* project for 14-16 year old students, which also used a narrative approach for progression towards an understanding of key ideas, noted:

> *As the project was dealing with a three-year period within a 5-16 continuum, the first step was to develop a curriculum 'map' outlining how the main ideas in each of the main strands of science content might be expected to develop over the 5-16 age range. A 'main strand of science' here means a major topic like forces and motion, electricity and magnetism, chemical change, or evolution. This 'map' in effect proposes an outline teaching sequence, or learning progression (Corcoran, Mosher, & Rogat, 2009).*
>
> *(Millar, 2016)*

This was also considered in the Kind review (2012, pp. 8-10) and the Harlen report (2015).

> *To convey the notion of progression in understanding it is not enough to state what is to be learned in terms of topics or concept words such as 'force', 'electricity' or 'materials'. To be useful the statements should indicate the level of understanding or relationships and connections intended at particular stages.*
>
> *(Harlen, 2015)*

This serves to highlight again the findings of the learning outcomes case studies: that the cultural and pedagogical complexities associated with implementing this scale of change are significant. This is particularly pertinent within education systems, such as the Irish system, where there is greater reward in external examinations for the acquisition of propositional knowledge, creating a back-wash effect into classroom pedagogies, and reducing the attention on the acquisition of procedural and epistemic knowledge.

Chapter 4: summary

Research indicates that all aspects of the intended and enacted curriculum should align with a clearly articulated and shared purpose. This implies that all elements within a newly developed specification, such as learning outcomes, key skills, assessment and curriculum content, should align with the stated purpose.

To inform this review and to learn from other jurisdictions whose curricular policy has also shifted away from prescriptive specification of content towards a more generic, skill-based approach articulated as learning outcomes, the NCCA commissioned *Learning Outcomes: An International Perspective (NCCA, 2019).* It acknowledges that there is widespread support within transnational policy circles for this shift in policy towards learning outcomes but highlights the cultural and pedagogical complexities associated with implementing this scale of change within education systems.

International experience of using learning outcomes signals how the failure to address the question of what knowledge is of most worth can result in curricular fragmentation and loss of coherence. The international perspectives paper notes that when learning outcomes are used to specify knowledge in curricular documents, teachers are expected to use constructivist forms of pedagogy in order for students to go beyond simply acquiring propositional knowledge. The importance of PCK is also highlighted in the report, in particular the ability to link facts to concepts and the role that progression plays in developing curricular coherence. This also enables students to develop deeper understandings, to make connections between different knowledge domains, and to be able to acquire procedural knowledge.

Harlen and Millar provide some examples of how curricular content could be structured to present a body of knowledge in a manner which facilitates learner progression, allows for deeper connections and supports a more coherent curriculum. Communication between all those using learning outcomes is essential in order to minimise the gap between the intended and the enacted curriculum.

5. Assessment in a new specification

Since the 2014 draft specifications were developed, there have been significant initiatives and policy decisions which have implications for assessment in any newly developed specifications. This chapter will discuss some of the implications, most notably progression from junior cycle and the inclusion of coursework components in all recently developed senior cycle specifications. In addition, the key findings from the NCCA commissioned research into coursework and practical assessments for upper secondary schools in international jurisdictions, will be outlined.

5.1 An assessment perspective

Osborne has argued that *for too long, assessment has received minimal attention (*Osborne, 1998, p.9*).* Osborne and Dillon (2008) 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. Millar (2012) views assessment as *an invaluable tool for the future of science education* and favours a *'backward design' approach to the planning of instruction*, by using assessment to clarify the learning objectives of lessons (Millar, 2016). Assessment in education has been the subject of research for decades, and the impact of high-stakes testing such as the Leaving Certificate examination on teaching and learning is well documented. Since the early 1980's there have been several reviews of such research (Crooks, 1988; Koretz et al., 1991; Black & Wiliam, 1998). A strong, common theme emerges from the findings: high-stakes testing has a backwash effect into daily learning and teaching. This has been echoed in our context in the SEC Chief Examiner Reports (SEC, 2013) and the report on the trialling of the practical assessments (SEC, 2018).

In light of all that has happened since the 2014 draft specifications were developed, and given the findings of the *Report on the Trialling of the Assessment of practical Work in Leaving Certificate Biology, Chemistry and Physics* (SEC, 2018), there is much to reflect upon with regard to how best to design assessment approaches for the new specifications. The reflections should focus on ways that will allow for fair and more varied opportunities for students to provide evidence of their achievements and how assessment can be used to measure experimental investigation skills as well as the broader competencies set out in the STEM Education Policy Statement (DES, 2017).

5.2 Progression from Junior Cycle

The Junior Cycle Science specification encourages teachers to *provide opportunities for students to investigate contemporary scientific issues, supporting students to make connections between science, other subjects and everyday experiences.* (NCCA, 2015) Students must complete two Classroom-Based Assessments (CBAs) during the three years of studying Junior Cycle Science. The first CBA is an Extended Experimental Investigation and the second is a Science in Society Investigation. The CBAs provide opportunities for students to become creators of scientific work and to enhance key skills such as being creative, communicating and working with others. The CBAs and the incorporation of junior cycle key skills are some of the curricular mechanisms by which students are assessed on how they communicate data from research and experimentation. One of the challenges will be to develop new specifications for senior cycle that can create a clear sense of progression and curricular coherence for both students and teachers.

For example, the dual approach to assessment articulated in the Framework for Junior Cycle (DES, 2015) proposes that, in whichever context it is used, assessment can and should be supportive of learning. For assessment to be meaningful, equitable and fair it must closely align to the type of learning and skills that are valued. Studies have found that factual knowledge tests are well suited to assessing the outcomes of teaching approaches based on knowledge transfer. But such tests are less adequate when it comes to assessing complex competencies (Booth, B., Hill, M. & Dixon, H. (2014)) or the outcomes of student-centred approaches to teaching and learning. In the interest of continuity, the development of assessment approaches and components for the new specifications will need, therefore, to consider a range of approaches that offer students multiple and appropriate opportunities to achieve. In so doing the backwash effect of high-stakes testing can support learning as well as ensuring continuity from junior cycle.

5.3 Assessment for certification in newly developed specifications

As previously outlined, the *Report on the Trialling of the Assessment of practical Work in Leaving Certificate Biology, Chemistry and Physics* (SEC, 2018), concluded that whilst the model for practical assessment could, in fact, broadly assess practical and analytical skills identified in the draft 2014 specifications, the concerns over its capacity to assess these skills in unfamiliar situations would have too much of a negative impact on alignment and could result in a critical loss of coherence.

All assessments are simply samples of a domain. In a high-stakes environment, such as the Leaving Certificate, the tendency can be for the curriculum to be diminished into *that which will be assessed (*Mansell W 2007; Stobart G 2008*).* This can give rise to the back-wash effect of teaching to the sample rather than the domain. The challenge for policy makers therefore is to design a specification with assessment opportunities that more closely match the domain. The current template for senior cycle specifications - organised into strands, presented in the form of learning outcomes and containing at least one coursework component worth at least 20% of the final marks - has the capacity to facilitate the alignment of assessment with a clearly articulated purpose of science education. It offers an opportunity to validly assess the skills of scientific practice and ensure these skills become an integral element of a modern coherent curriculum for senior cycle science education.

Coursework components allow skills and knowledge to be assessed over a longer period of time than can otherwise be assessed by the written examination. For example, the Leaving Certificate Agricultural Science specification, which will be implemented in schools from September 2019, describes the *Individual Investigative Study*, in which:

> *each student is required to carry out an individual investigative study related to a topic in agricultural science, including any research that might be appropriate. The individual study is an investigative activity which is based on and draws from a thematic brief set annually by the State Examinations Commission at the commencement of the two-year course. It is conducted over the two years of the course and facilitates study of particular areas in greater depth and which may be of local or regional agricultural significance. It enables students to see at a practical level how science underpins and supports agricultural practices, processes and research.*
>
> *(NCCA/DES, 2018a)*

Coursework briefs for specifications designed since 2017 have been common briefs, and generally common thematic briefs, for all students. Common briefs have the capacity to deepen coherence across the entire curriculum for all students, since students can engage with the one brief irrespective of the level of differentiation. In addition, they afford students the scope to continue to engage with the curriculum at all levels, up to and beyond the time of submission. Issues and talking points around the role of differentiation are highlighted in the *Interim report of review of senior cycle education* (NCCA, 2019b).

5.4 An international perspective

The principal reason for including assessment of practical science skills in high-stakes examinations internationally is because it adds the capacity to measure processes and applications of science in a way that cannot be measured in a written examination. Indeed, the difficulty in finding a model of practical assessment that assesses the desired outcomes, and in the process enhances curricular coherence, explains why this area of assessment is undergoing continuous research and development. As part of the process of developing a background paper, NCCA commissioned research into coursework and practical assessments for upper secondary schools in international jurisdictions. The research, *Coursework and practical assessment in senior secondary science: the perspective from international jurisdictions* (NCCA, 2019c), focusses in particular on arrangements in England, Singapore, Scotland and Hong Kong and is also informed by the International Baccalaureate Diploma Programme and investigations into top-performing PISA countries. The final report can be accessed on the NCCA website at www.ncca.ie[1]. The report concluded that the international jurisdictions seek to:

> - *ensure that practical science assessments do not unduly increase the workload of both teachers and students, […] by limiting the time allowed for the coursework assignment (e.g. through controlled conditions, Scotland)*
> - *ensure the validity, reliability, robustness and comparability of the assessments*
> - *enable the assessments to take account of the full range of student ability and support differentiation, so that assessment judgements discriminate effectively*
> - *ensure the important contribution of the development of practical skills to senior secondary science qualifications by including the results of practical science assessments in the final mark for the qualifications; practical science assessment commonly contributes 20% of the final mark.*
>
> *(NCCA, 2019c)*

[1] Link to international research will be updated

Chapter 5: summary

Since the 2014 draft Leaving Certificate science specifications were developed, there have been significant initiatives and policy decisions which have implications for assessment in any newly-developed specifications – the most relevant being the introduction of two classroom-based assessments in Junior Cycle Science and the findings of the SEC trialling of the assessment of practical work in Leaving Certificate biology, chemistry and physics. Research suggests it is the responsibility not just of the teacher but also the assessment system to shape the pedagogy which enacts the intended curriculum. The request to review the draft specifications means that assessment can now be more strongly aligned with a clearly articulated purpose of a new senior cycle curriculum.

All new specifications designed since 2016 have included at least two assessment components, comprising a final written examination and at least one coursework component. Coursework briefs for specifications designed since 2017 have been common briefs, and generally common thematic briefs, for all students. The template for newly designed specifications allows for consistency and coherence across the structure of all three senior cycle science subjects, and has the capacity to facilitate progression from junior cycle.

International research shows that other jurisdictions strive to use coursework assessments to take account of the full range of student ability and support differentiation. The intended purpose of coursework assessment in recently developed specifications, such as Leaving Certificate Agricultural Science, reflects the findings of the international research.

6. Conclusion

This paper argues for curricular coherence and highlights the integral role that purpose plays in achieving coherence. This concluding chapter brings into focus some issues for consideration when developing a clearly articulated purpose for senior cycle science education

The STEM Education Policy (DES, 2017) mentioned in chapter 2 acknowledges the fact that Science, Technology, Engineering and Mathematics (STEM) are at the heart of a technological revolution which is transforming the way we live and the way we work. If Ireland is to be at the forefront of this transformation, we must be a leader in nurturing, developing and deploying STEM talent. The implication of the importance of the key STEM principles (DES, 2017, p.9) outlined in section 2.6 is that in articulating the purpose of senior cycle science education, we consider the question: *What are we building knowledge for*? The principles situate the acquisition of bodies of discipline-specific knowledge as a *means* of educating young people as opposed to *the end* of education itself. Within this STEM framework science education is important for everyone, including those who do not wish to pursue a career in science.

Chapter 4 discussed how using learning outcomes effectively in a coherent curriculum can bring clarity to the types of knowledge students will acquire, place emphasis on the knowledge, skills, values and attitudes students will learn, as well as focusing on the subject matter of the course. They will play a significant role in this review in ensuring that the objectives of the physics, chemistry and biology specifications, the learning and teaching strategies adopted, and the assessment used are consistent with each other and with the overall purpose.

In conclusion, one of the key tasks for the review is to consolidate the acquisition of key propositional knowledge (*knowing that*) while fostering the acquisition and assessment of procedural (*knowing how*) and epistemic (*knowing about*) knowledge. In the new specifications for senior cycle, embedding senior cycle key skills and scientific practices in learning outcomes, aligned to a shared vision and with due regard to international developments in science education, has the potential to produce a contemporary specification that will be relevant for all students and develop their scientific literacy as well as their understanding of the natural world and preparedness for the future life, study and work.

Annexe 1 : Subject specifications in senior cycle

All senior cycle specifications for subjects offered within the Leaving Certificate Established programme will have a number of features in common. They will:

- be outcomes-based
- reflect a continuum of learning with a focus on learner progression
- include a focus on all five key skills and literacy and numeracy
- strive for clarity in language and for consistency in terminology.

The specification for each subject will include:

- Introduction
- Rationale
- Aim
- Objectives
- Structure
- Assessment

Introduction to senior cycle	This will be common to all specifications and will summarise the main features of senior cycle education.
Rationale	This will describe the nature and purpose of the subject as well as the general demands and capacities that it will place on, and require of, students. The text will, as appropriate, aim to draw attention to challenges and any access issues associated with study of the subject for students with specific needs or disabilities.
Aim	A concise aim for the subject will be presented.
Objectives	A broad outline of the skills, values and knowledge, consistent with the aim, that the students will develop during the course.
Structure	An overview of the subject will illustrate how it is organised and will set out the learning involved in strands and learning outcomes.
Assessment	This section outlines the assessment component/s through which students will present evidence of learning for assessment for certification.

In general terms, the specification should be aligned with levels 4/5 of the National Framework of Qualifications. Some specifications may have distinct characteristics due to specific learning areas within the subject. The specification will be designed for 180 hours of class contact time and there will be an ordinary and higher level.

Annexe 2: Brief for the review of leaving certificate physics, chemistry and biology

The review of Leaving Certificate physics, chemistry and biology will involve developing curriculum specifications for each subject in line with the template for specifications for all senior cycle subjects.

The key skills of senior cycle and the skills of literacy and numeracy, as appropriate, will be embedded in the learning outcomes of the specification.

The specifications will be completed for Council by autumn 2020.

More specifically, the development of the new specifications will address:

- progression and continuity from Junior Cycle Science
- a curricular balance that underpins propositional knowledge and supports the acquisition of procedural and epistemic knowledge
- sustainability and how such contemporary issues might be explored by learners
- how students will be assessed; the integration of a coursework assessment component allowing for the assessment of inquiry-based learning, critical thinking and elements of experimental investigation, into each of the three subject specifications
- how to widen the appeal of the subjects in order to meet the targets of the STEM strategy and re-balance gender uptakes
- how to encourage student agency and an associated capacity for lifelong learning
- how to differentiate on conceptual depth to meet the needs of a diverse range of students; for example, those who wish to progress to STEM careers through third level or apprenticeships, or those who will pursue other pathways outside STEM but still need to be scientifically literate citizens
- how to embrace technology in the learning, teaching and assessment associated with the specification, in such a way that students are digital consumers and creators
- the identification of supports necessary for successful enactment.

The work of the Leaving Certificate science subject development groups will be based, in the first instance, on this brief. In the course of its work and discussions, refinements of some of these points and additional points may be added to the brief.

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