From Curriculum to Classroom in Upper Second Level Science

By

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A thesis presented to Dublin City University for the degree of Doctor of Philosophy

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Declaration

I hereby certify that this material, which I now submit for assessment on the programme of study leading to the award of Doctor of Philosophy is entirely my own work, that I have exercised reasonable care to ensure that the work is original, and does not to the best of my knowledge breach any law of copyright, and has not been taken from the work of others save and to the extent that such work has been cited and acknowledged within the text of my work.

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Abstract

Education in Ireland has gone through a significant period of change since the 1980s. Upper second level education has been the subject of extensive consultation and review, and revised specifications for Leaving Certificate biology, chemistry and physics were developed by the National Council for Curriculum and Assessment during the period 2006-2014. The revised specifications are written as learning outcomes in which the key skills of information processing, being personally effective, working with others, communicating and critical and creative thinking are embedded. Curriculum development in Ireland reflects international practice, where development of key competences/skills is a fundamental theme underpinning recently developed curricula. Whilst knowledge and understanding of science concepts and theories is as important as ever, what learners are able to do with that knowledge and understanding is equally, and increasingly, important. Although curriculum development in Ireland is in line with curriculum development internationally, this study focuses on the local issues associated with curricular change, in particular the translation and communication of learning outcomes.

The construction of learning outcomes is a *complex, non-linear, interacting system* which teachers will need to deconstruct in order to fully understand them. Building on key literature, this study develops two organising frameworks that facilitate analysis of learning outcomes and of assessment items. Understanding the kinds of learning experiences that develop skills in students will contribute to curricular coherence, without the need for curriculum control.

The study describes two design based research projects in which teachers and students actively contributed to the process of curriculum development. The teachers worked at the interface between policy and research, and brought their experience and knowledge to the curriculum design process. The first project was concerned with pedagogy, the second with assessment. The outcomes of both projects informed the development of the upper second level science curricula in Ireland, and have set the scene for further developmental work.

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My greatest personal debt is to my three children, Tim, Coco and Molly, without whose support and patience I would not have been able to complete this thesis; and to my mother who made me recognise the value of education.

1 Introduction

1.1 Research question

The aim of the research presented in this thesis is to identify strategies that are necessary to support teachers in curriculum change. Through work with teachers and schools to identify and describe the kind of support that will enable teachers to translate and communicate learning outcomes of revised curricula in upper second level biology, chemistry and physics in the way that curriculum developers intended them to, the project outcomes should inform the achievement of curricular coherence across schools.

The thesis initially describes the process of curriculum development in Ireland, in particular in the Leaving Certificate sciences, paying particular focus on the local issues. It places the development of science curricula and specifications in Ireland in the wider international context.

Across Europe and the English-speaking world, outcomes-based curricula, that are student centred and advocate active pedagogies have been adopted to varying degrees. Recently revised curricula show a number of similar policy trends including: a move from the explicit specification of content towards a more generic, skill-based approach; a greater emphasis on the centrality of the learner; and greater autonomy for teachers in developing the curriculum in school (Siennema & Aitken, 2013). The constructive forms of pedagogy associated with these curricula encourage the development of deep learning (Biesta, 2014).

Ireland has followed these international trends, and the revised specifications for Leaving Certificate biology, chemistry and physics share these comonalities. Rich, open learning outcomes allows for flexibility and for teachers to use their expertise and professional judgement in planning for teaching, learning, and assessment. Specifications that describe a process rather than a product of learning are new to teachers in Ireland, and careful consideration must be given of the best way to provide guidance so that learning outcomes are interpreted in the way that the developers intended. The nature of the support material provided is critical to the professional development of teachers and to the success of revised curricula.

1.2 Research method

Educational design based research was considered the most appropriate methodology for this research as it uses experiences of practitioners to identify practical problems, for which experts and practitioners co-construct a theoretical framework to develop and try out solutions. The solutions are tested in classroom settings by practitioners and students, after which there is reflection and discussion development of documentation and design principles. Working with teachers and learners in authentic classroom settings provides information that helps us to understand how young people learn within school settings and identify the support material that is necessary to ensure that the intended learning will happen in these settings. The questions that this research posed would not have been answered by empirical research, as the process was an iteritive one in which there was a continuous refinement of ideas in order to develop a theoretical framework, rather than one which relied on an intervention affecting an eventual outcome

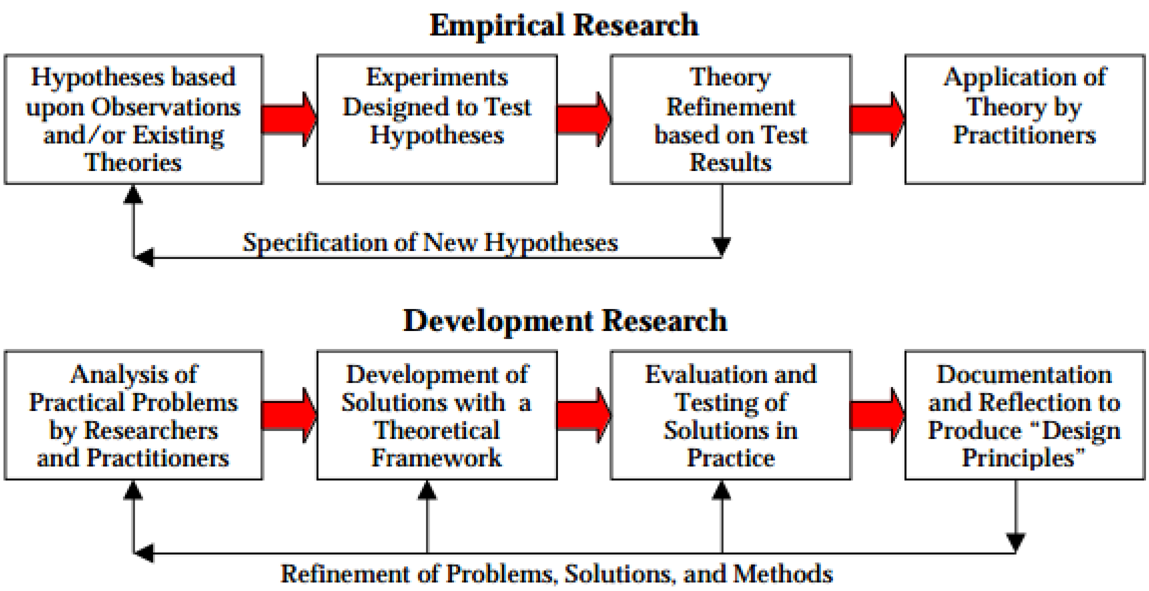

Figure 1-1 Empirical and developmental approaches to educational research (Reeves, 2000)

The comparison between empirical research and design-based, developmental research is described by Reeves (Reeves, 2000) (Figure 1-1).

Teachers that are currently teaching senior second level science were invited to participate in each of the educational design based research projects. The teachers were self-selected, the students were from either the fifth or sixth year of upper second level, i.e. currently doing the Leaving Certificate science course.

As part of the research, two design Based Research projects were carried out:

Project one: Asteroids Impacts and Craters, aimed to:

- demonstrate how learning outcomes can translate into classroom practice in which learners develop key skills as they encounter physics concepts in an authentic context;
- illustrate key skills, and higher order thinking skills embedded in learning outcomes;
- elucidate the evidence that would demonstrate the achievement of learning outcomes and reaching personal targets.

Project two: Assessment of practical science, aimed to:

- generate examples of different kinds/elements of practical science assessment
- generate the content and items (tasks/questions etc.) that the different assessments give rise to
- provide a view of what the different kinds/elements of practical science assessment look like in practice
- determine the cost, both financial and logistical of running large scale practical assessment.

These projects will be described in detail in Chapter 6.

1.3 A background to education in Ireland

Education is highly valued in Ireland; it is considered pivotal to economic, social and cultural development in Irish society. There is a high level of public interest in education, which is reflected in the partnership approach adopted by the Government in the formulation of education policy across the sectors from Early Childhood education to Leaving Certificate. The structure of the Irish education system is outlined in Appendix 2.

Education at upper second level in Ireland is aimed at a diverse range of learners as Ireland has one of the highest retention rates to upper second level education in Europe. According to a report published in 2014 by the Department of Education and Skills (DES), over 90% of the cohort of students who entered junior cycle in 2007 stayed in education to complete senior cycle. Furthermore, the retention rates for students who began junior cycle in 2007 are almost 8% higher than those who began in 1997 (DES, 2014). The trend goes across social sectors; the Government has initiated a programme, Delivering Equality of Opportunity in Schools (DEIS) 2005. DEIS is the Department of Education and Skills (DES) policy instrument to address educational disadvantage, it focuses on addressing and prioritising the educational needs of children and young people from disadvantaged communities, from pre-school through to second-level education (3 to 18 years). The retention rates in DEIS schools continues to increase and is now at 80.4% for those who entered second level in 2007. The report further states that Ireland also has one of the highest proportions of persons aged 20-24 with at least a higher secondary education in the EU (8th of 28 countries). Ireland's rate of 87% is significantly above the EU average of 80% (DES, 2014).

Ireland has one of the highest numbers of students progressing to third level and further education in Europe. In 2013, 52,767[1] students sat the Leaving Certificate, and 46,281 students accepted places in third level or further education courses (level 6, 7 or 8)[2]. The acceptance figures include mature students and others who did not sit the Leaving Certificate in 2013; however, they indicate the very high percentage of students who progress from second level to third level education. Figure 1-2 shows that this is a trend that is increasing (Patterson, 2013).

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[1] https://www.examinations.ie/statistics/statistics_2013/LC_Sits_by_County_and_Gender_201 3–pdf

[2] http://www.hea.ie/sites/default/files/cao_acceptance_paper_hea_201 3–pdf

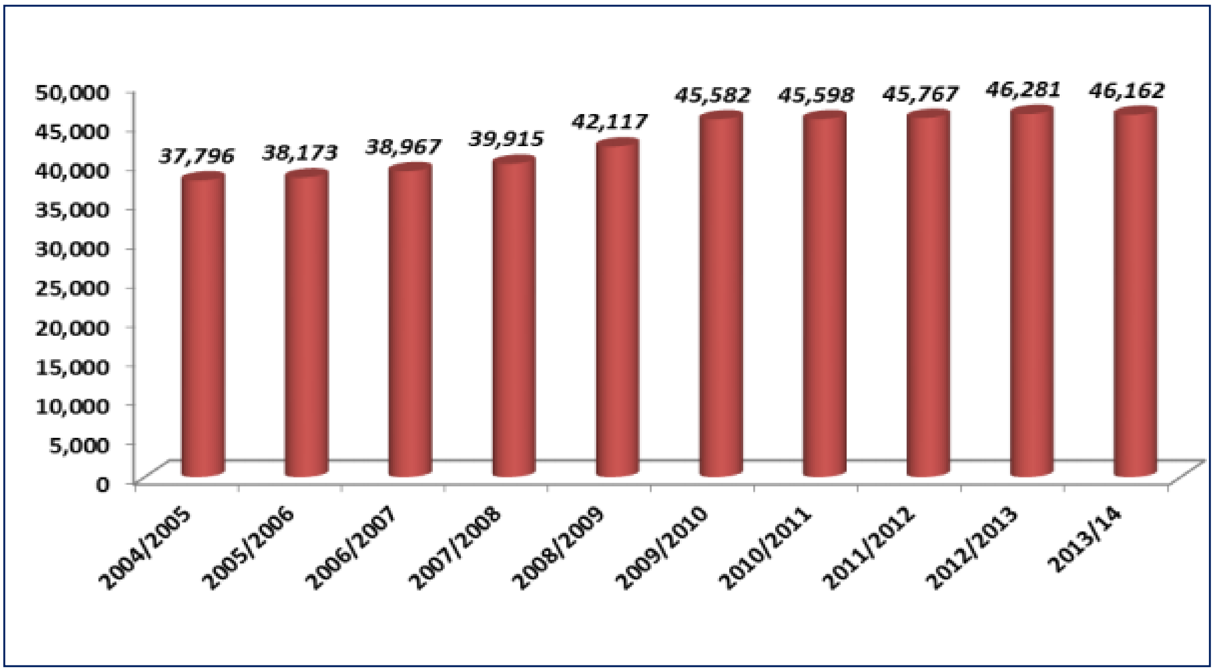

Figure 1-2 Total Acceptances (Level 6/7 & 8) 2004/05 to 2013/14.

The last number of years have been characterised by a programme of revision and updating of senior cycle education in Ireland. A key objective of the revisions is to ensure that the broad range of abilities, interests, learning styles and special needs of students are catered for. The changes in Ireland reflect changes in upper secondary education internationally where a consensus has emerged in many education systems about the dimensions of learning that are appropriate for learners and young people in the 21st century. A recent OECD review, citing a number of international sources, suggests that learners need to have opportunities to:

- Acquire relevant knowledge;
- Develop a range of critical skills, including both fundamental access skills such as literacy and numeracy, and higher order skills such as creativity, critical thinking, problem solving, communication and collaboration;
- Develop behaviours, attitudes and values, including abilities that enable the learner to care for him/herself, to act as a responsible citizen, and to be adaptable and resilient;

- Learn how to learn: to become aware of one's own learning styles and to acquire the ability to develop and enhance one's own learning approaches (Schleicher, 2012).

The emerging trend in education internationally is on designing curricula that promote development of skills in learners as they progress through school. The skills, identified by international research organisations such as the OECD, have come to be known as 21st century skills. The label *21st century* is misleading, the identified skills have always been valued in education, but have received greater attention in curriculum design recently as the needs of the workplace and the economy has changed over the past decades (Silva, 2009). Critics of the *skills movement* argue that over-emphasis on skills development downgrades knowledge, as attention is taken away from learners acquiring a broad range of fundamental knowledge. Assessment is seen as a driver in curriculum, however it is possible that the explicit inclusion of 21st century skills in assessment may provide the driver to clarify the relationship between factual knowledge, higher order thinking skills and personal and social skills.

1.4 Thesis structure

Building on key literature, this thesis develops two frameworks to analyse the learning specification and assessment items, and uses the framework to guide and inform further development. As part of the curriculum development, interpretation and translation of specifications to teachers and schools was informed by two design based research projects. The first project, entitled *Asteroids, Impacts and Craters* investigated how the embedded skills in learning outcomes translated into classroom practice; the second, *Assessment of Practical Science*, investigated ways in which practical science could feasibly be assessed in Ireland, with all of the constraints inherent in Leaving Certificate assessment.

The thesis comprises seven chapters. Chapter one outlines the research question and the methods used. Chapter two provides an overview of the developments in Irish post-primary education over the past two decades leading up to the review of Leaving Certificate science. Chapter three traces the historical development of science education internationally, and places the review of science in Ireland in the context of international developments in science education. This includes an examination of the changing role of teachers as agents of change, and also of schools and practitioners in curriculum development. This chapter also describes the international move towards learning outcomes, and compares developments in Ireland with international developments.

Chapter three takes a broad look at curriculum development, and describes different models with particular reference to England, Hong Kong Australia, Ontario, Scotland, New South Wales and the International Baccalaureate. The chapter also examines how practical science is included in curricula from different jurisdictions. The literature about the role of practical work and its effectiveness is reviewed, and a model of how to measure the effectiveness of practical assessment is proposed.

Chapter four proposes a three dimensional organisational framework for curriculum development. The framework is based on Anderson and Krathwohl's revised taxonomy (Anderson & Krathwohl, 2001), and includes a key skills dimension. This chapter describes how the organising framework was applied at key stages during the curriculum development process to monitor the range and breadth of key skills and of cognitive demand along with the knowledge dimensions of the learning outcomes. The results provided a snapshot of the development process, and identified issues and informed the choice of the nature of the curriculum development support work with schools. Chapter five focuses on measuring learning outcomes and critiques current Leaving Certificate assessment in Ireland. Assessment frameworks used to measure assessment demands in terms of scale of demand of tasks are critiqued, and an assessment framework is developed and applied to examples of assessment. Chapter six describes two design based research projects carried out in collaboration with teachers.

Finally, chapter seven discusses the implications of the study, including implications for continued professional development and further research. The chapter concludes by delineating recommendations, and in addition outlines the next stage of the work.

2 Context and background

This chapter provides a context for and a background to the review of senior cycle that led up to the development of the new specifications for Leaving Certificate biology, chemistry, and physics. It starts by considering the curriculum developments that occurred at upper second level education in Ireland during the 1990s and proceeds to describe the subsequent review of senior cycle in the 2000s that led to an overarching vision and principles of senior cycle. It goes on to describe how the key skills framework and the common template for senior cycle provided the foundation for the development of the Leaving Certificate specifications for biology, chemistry and physics. It presents some of the recent discussions on the Leaving Certificate as a selection tool for higher education, and how that has influenced teaching, learning and the experience of senior cycle. The final section provides a brief overview of the development of science education more generally, and shows the overlap between senior cycle developments in Ireland and international trends in science education.

2.1 Senior cycle developments

2.1.1 The National Council for Curriculum and Assessment (NCCA)

The National Council for Curriculum and Assessment (NCCA) is a statuary body with responsibility for advising the Minister for Education and Skills on matters relating to curriculum and assessment. The Council is a representative structure, the membership of which is determined by the Minister for Education and Skills. The 25-member council comprises nominees of the partners in education, industry and trade union interests, parents' organisations and one nominee each of the Minister for Education and Skills and the Minister for Children and Youth Affairs (Table 2-1). New curricula must be approved by Council and its sub-groups at each stage of development. The sub-groups predominantly comprise practicing teachers nominated by the partner organisations. The Council is supported by four Boards (one each for Senior Cycle, Junior Cycle, Primary and Early Childhood), who are in turn supported by Curriculum Development groups (Figure 2-1).

- Joint Managerial Body
- Department of Education and Skills
- Irish National Teachers' Organisation
- Church of Ireland Board of Education
- Education and Training Boards Ireland
- Nominee of the Minister for Children and Youth Affairs
- Association of Secondary Teachers, Ireland
- Teachers’ Union of Ireland
- Irish Federation of University Teachers
- National Parents Council Primary
- National Association of Boards of Management in Special Education
- Irish Business and Employer’s Confederation
- Irish Congress of Trade Unions
- National Parents Council Post-Primary
- Foras na Gaeilge
- Catholic Primary Schools Managers’ Association
- State Examinations Commission
- Association of Community and Comprehensive Schools

Table 2-1 NCCA Education partners

Curriculum development groups established by the NCCA provide a strong, representative and responsive basis for its curriculum and development work. Each group consists of nominees from teacher and management bodies, Department of Education and Skills, the State Examinations Commission, higher education interests and subject associations. Prior to the establishment of a development group, Council agree the remit of the group and the duration of its term of office.

Nominees to each of the development groups complete a resumé indicating the subject or curriculum and assessment development experience she/he possesses relevant to the work in hand. The purpose of this is to allow for obvious gaps to be identified early, and addressed by co-option of additional members to offer specialized expertise if required. In order to gain access to as wide a pool of available expertise as possible, and encourage the participation, for example, of early career professionals and people who may be working outside the formal education sector, NCCA seek expressions of interest through the same pro-forma resumé from people interested in participating in a development group. Two members of each development group may be appointed in this manner.

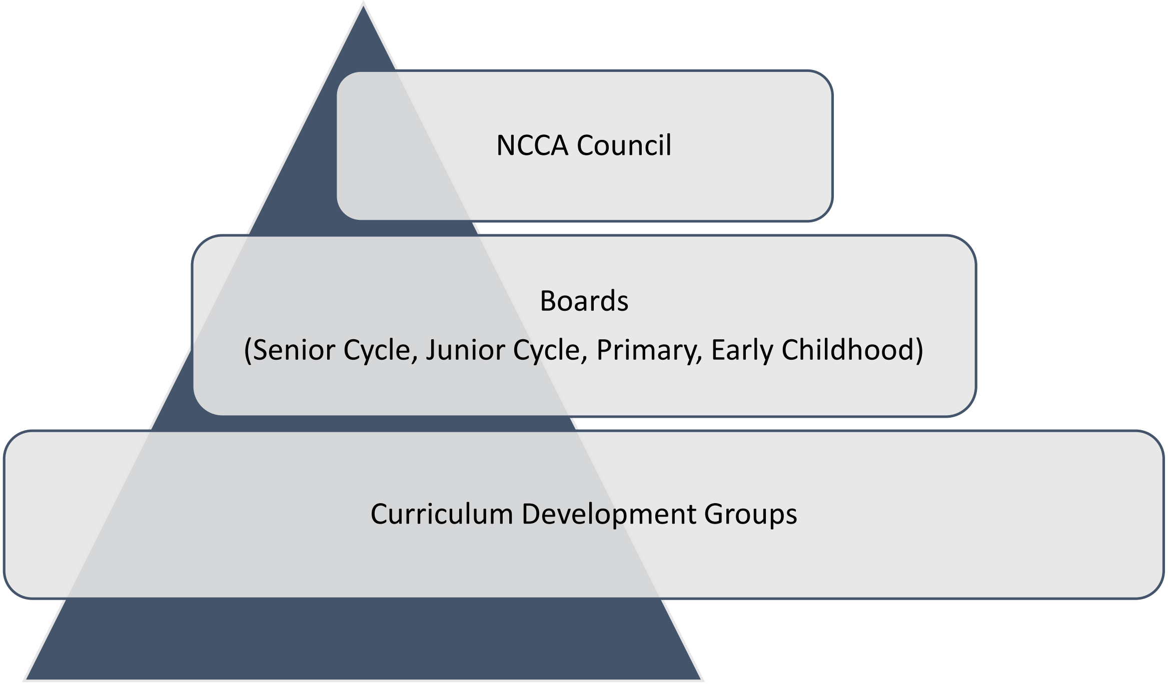

Figure 2-1 NCCA structures

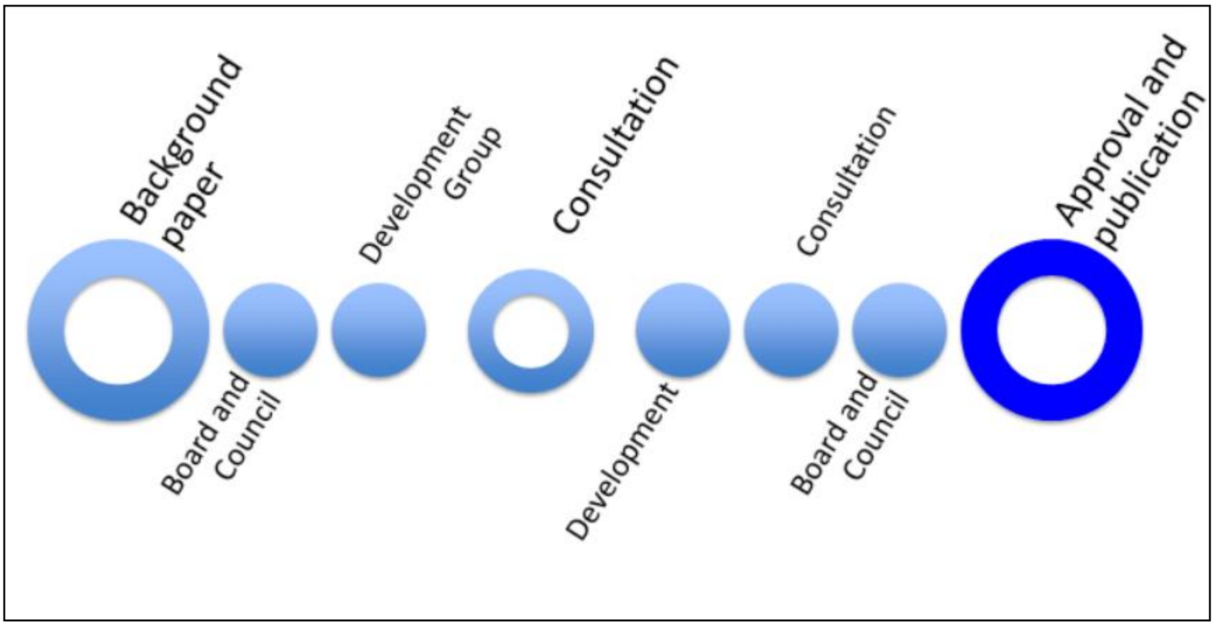

Figure 2-2 Developmental stages for new specifications

Typically, new or revised curricula go through several developmental stages prior to being approved for implementation, as shown in Figure 2-2, starting with the background paper.

The roles of Council, development groups and the NCCA executive in the process of development is outlined in Table 2-2 (NCCA, 2012b)

Stage	Development of specification	NCCA Roles
Curriculum shaping	A draft background paper for the subject/area under review, the final section of which would be a brief for the group	Council
	A Project Plan	Executive
	Establishment of a development group	
	Initial Meeting/s of the development group to finalise and expand the background paper	Development group and Board.
	Background paper approved by Council for consultation	Council
	Report of the consultation to development group, Board, and Council and amending of brief if necessary	Executive support
Curriculum development	Meetings of the development group	Development group with executive support providing access to research and engagement with networks.
	Progress of development activity available on website after each meeting or couple of meetings (depending on stage of the work)	
	Final draft specification considered by relevant Board	
	Sign off on specification by Board and by Council for consultation	
Curriculum Implementation	Meeting/s to act on feedback and finalise the specification	Board, Executive, development group
	Final briefing of publishers and other interests	Executive
	Preparation of memo on implementation	Executive
	Specification presented to Board for agreement to seek Council approval for issue to the Minister for Education and Skills	Executive

Table 2-2 Overview of curriculum and assessment development process

2.1.2 Background to the review of senior cycle

In the early 1990s the NCCA initiated a review of senior cycle in Ireland. The need for such a review arose from the requirement to establish continuity with changes introduced in the junior cycle in the late 1980s, and also growing criticisms, both from within Ireland, and externally of the education system in general, and the Leaving Certificate (established) in particular. The OECD Review of National Policies for Education: Ireland (OECD, 1991) focused on the inequality inherent in the Irish education system at that time and its impact on the educationally disadvantaged and those with special educational needs; it also criticised the over-academic nature of the curriculum, the lack of choice available to learners with differing abilities and aptitudes, and the limited range of assessment approaches and pedagogical methods in use.

In 1993 the NCCA published A Programme for Reform - *Curriculum and Assessment Policy Towards the New Century* (NCCA, 1993). It encompassed NCCA policy statements and recommendations on issues arising from the publication of the Government's Green Paper Education for a Changing World (DES, 1992) and the debate which followed. The vision was to allow for a better balance between knowledge and skills in the educational experience of senior cycle students, and the promotion of the kinds of learning strategies associated with participation in the knowledge society. The original restructuring proposed by the NCCA provided for a flexible approach to curriculum components. It proposed that students would take courses from within two national programs, the Leaving Certificate and the Senior Certificate. The idea was that there would be two options for senior cycle, and that students would be able to mix and match between modules in the more academic Leaving Certificate and the more vocational Senior Certificate. There was also provision that assessment for certification would happen twice during the course, at the end of fifth year and at the end of sixth year, thus lessening the burden of the assessment for certification.

The full extent of the reforms were not implemented. The Education White Paper in 1995 (DES, 1995) referred to a sustained effort of change rather than large-scale reform.

The approach to the implementation of change will be important. Effective change does not occur instantly. The implementation of the policies and decisions described in this White Paper will require sustained effort over time from all involved in education. The White Paper provides the strategic direction.(DES, 1995)

Although the Leaving Certificate (established) did not change, there were significant changes to other senior cycle programs, amongst other things, the introduction of Transition Year in 1994, and the Leaving Certificate Vocational Programme (LCVP) and the Leaving Certificate Applied (LCA) in 1999.

The Leaving Certificate (established) was ring-fenced and remained the basis for admission to higher education. The net effect of this was that resources were channelled towards the development of teaching and learning approaches of the new Leaving Certificate options, the LCA and the LCVP rather than to the Leaving Certificate (established). As a result of this ring fencing, the review of the Leaving Certificate (established) during the 1990s was very limited in its nature despite the appetite at the time for large-scale reform. Although there were changes to many of the syllabuses in the Leaving Certificate (established) including biology, chemistry and physics, the assessment didn’t change and so the effect of the syllabus change was limited to what was learned rather than the manner in which it was learned.

During this period, the *Commission on the Points System: final report and recommendations* (Ireland, 1999) suggested that a substantial review of the Leaving Certificate (established) as an educational programme was overdue. It recommended that such a review should be fundamental, addressing matters such as the nature of the senior cycle experience, issues of curricular breadth and balance and of differentiation, the broadening of assessment approaches, and the establishing of provision that would contribute to social cohesion. The relationship of the Leaving Certificate (established) to other senior cycle programmes would also need to be reconsidered in these contexts, echoing the view of the Senior Cycle committee that the Leaving Certificate should not be treated in isolation. Many of these concerns were also echoed in the findings of the NCCA’s research study, *From Junior to Leaving Certificate – A Longitudinal Study of 1994*

Junior Certificate Candidates who took the Leaving Certificate Examination in 1997: Final Report (Millar, D., Kelly, D., 1999).

2.1.3 Reigniting the discussion

At the start of the new millennium, the NCCA restarted the discussion and debate on reform of senior cycle education and the Leaving Certificate (established) in particular. During the debates and discussions around the development of the new senior cycle options introduced in 1994, there was a lot of attention given to the aim and objectives of the senior cycle programme; however the Leaving Certificate (established) was still considered very much on a subject by subject basis with no overall vision or set of principles. In 1998, an internal draft discussion paper, *The Established Leaving Certificate and its Subjects,* was presented to the NCCA curriculum development group with responsibility for senior cycle. The paper presented a rationale for an overhaul of the Leaving Certificate (established); following consideration of the paper, and extensive discussion it was concluded that, as an educational program, the Leaving Certificate (established) could not be treated in isolation, and should be included in the future development of senior cycle education as a whole.

In 2002 the NCCA published a discussion paper *Developing Senior Cycle Education: Consultative Paper on Issues and Options* (NCCA, 2002). This marked the start of an extensive consultation on senior cycle. The progress of that consultation is outlined in Table 2-3.

The paper suggested that for most learners, the most important outcome of senior cycle education amounted to *getting the Leaving*. While much had changed during the 1990s in senior cycle education, the fundamentals for the large body of learners following the Leaving Certificate (established) remained the same. The discussion paper was the springboard for an extensive consultation to gather the views of learners, parents, teachers, school management, educational and social bodies, and other interested individuals and groups, on how senior cycle should develop into the future. The paper suggested that the strengths of the current system should be built on, but with greater emphasis on learners taking more responsibility for their own learning. The retention rate to Leaving Certificate was growing and greater numbers of learners with diverse learning needs were staying in education for longer. It was further suggested in the paper, that in a time of significant social, economic and cultural changes, a different kind of learner centred education was required with an emphasis on the development of knowledge and deep understanding, on learners taking responsibility for their own learning, on the acquisition of key skills, and on the processes of learning (NCCA, 2002).

The interest in the future of senior cycle is evident from the number of people who participated in the consultation. A total of 1,813 people participated in the consultation. In its report on the consultative process (NCCA, 2003a) , the NCCA noted that the term *senior cycle* generated confusion, because in Ireland, senior cycle education is referred to as the *Leaving Cert*. As one student put it: *we don't really have senior cycle education, we just do the Leaving* (*student, consultation questionnaire*). The report further commented that *doing the Leaving* is a particularly Irish experience that does not have an equivalent in any other education system. The responses to the consultation confirmed the strong feeling that as an objective of senior cycle education, *getting the leaving* attracted too much attention. The consultation and the discussions and seminars that followed it extended until May 2005, at which time the NCCA issued extensive and detailed advice on the future of senior cycle education to the Minister for Education (Table 2- 3), as given in *Proposals for the Future Development of Senior Cycle Education in Ireland* (NCCA, 2005).

Date	Event	Document
December 2002	NCCA published a consultation paper on senior cycle education.	Developing Senior Cycle Education: (NCCA, 2002)
January 2003	An online consultative questionnaire issued to all schools.	Consultation questionnaire(NCCA, 2003b)
April 2003	NCCA hosted the first of two seminars on senior cycle education: *Developing Senior Cycle Education: Key Issues*.	
February-April 2003	NCCA held 34 briefings for partner organisations.	
May 2003	NCCA hosted the second seminar on senior cycle education: *Changing Structures in Senior Cycle Education*.	
June 2003	NCCA held bilateral meetings with each of the partner organisations.	
August 2003	NCCA published the findings of the online survey on senior cycle education.	*Online Survey Results* (NCCA, 2003c)
September 2003	NCCA published a report on the consultations.	*Report on the Consultative Process* (NCCA, 2003a)
September 2003	NCCA held a national forum on the directions for development of senior cycle education.	*Directions for Development of Senior Cycle Education, booklet*(NCCA, 2003d)
January – March 2004	NCCA carried out school-based research into the views of teachers, students, parents and school management.	Video presentation- *Developing senior cycle education* (NCCA, 2004a)
June 2004	NCCA issued advice on the future direction of senior cycle to the Minister for Education.	*Proposals for the development of Senior Cycle Education* (NCCA, 2004b)
May 2005	NCCA issues more extensive and detailed advice on the future of senior cycle education to the Minister for Education.	*Proposals for the Future Development of Senior Cycle Education* (NCCA, 2005)

Table 2-3 Senior cycle review 2000-2005

The advice contained in *Proposals for the Future Development of Senior Cycle Education in Ireland* was not implemented in full; however, in a letter to the NCCA, the then Minister for Education Mary Hannifin indicated that while the DES were not in a position to implement the full set of proposals, they were supportive of continued reform of senior cycle on a subject by subject basis. The three Leaving Certificate science subjects were to be amongst the first set of subjects to be reformed.

2.2 The Leaving Certificate – Gateway to third level

The Leaving Certificate examination serves a number of purposes: it offers an end-of-school qualification; it supports and rewards learning in a senior cycle that aims to prepare learners for the next phase of learning, and for life; and it supports the selection mechanism for entry to further and higher education. In recent years, there has been much discussion and debate about how the role of the Leaving Certificate as a route to higher and further education has come to dominate.

In Ireland selection to higher education, commonly referred to as *the points system*, is based on grades obtained in the Leaving Certificate examination. The points system was developed and is administered by the Central Applications Office (CAO). The function of the CAO is to process applications for entry to first year undergraduate courses centrally. At present, there are 45 higher education institutions within the CAO system catering for some 77,000 applicants, offering 1,380 courses at National Framework of Qualifications Levels 6, 7 and 8[3]. The CAO allocates points to learners based on the grades they achieve in the Leaving Certificate examination, and places within higher education institutes are allocated based on points achieved. The point allocations have been collectively agreed by the third-level institutions involved in the CAO scheme (see Table 2- 4.)

[3] Statistics obtained from http://www.cao.ie/

Percentage	Grade	Points Awarded at each level		
		Higher	Ordinary	Foundation
90 – 100	A1	100	60	20
85 – 89.99	A2	90	50	15
80 – 84.99	B1	85	45	10
75 – 79.99	B2	80	40	5
70 – 74.99	B3	75	35	
65 – 69.99	C1	70	30	
60 – 64.99	C2	65	25	
55 – 59.99	C3	60	20	
50 – 54.99	D1	55	15	
45 – 49.99	D2	50	10	
40 – 44.99	D3	45	5	
25 – 39.99	E			
10 – 24.99	F			

Table 2-4 Points allocation for Leaving Certificate grades

(Note: there are some adjustments for some subjects for some courses within particular institutions)

The reform of assessment and certification at senior cycle, and in particular of the Leaving Certificate (established), attracted considerable attention during the course of the review (Figure 2- 3). In addition, a report from the Commission on the Points System (1999) highlighted a number of damaging effects attributed to the points system. Those effects included: a negative impact on learners' personal development; the choice of subjects by learners is determined by achievement of maximum points for entry to third-level education; a narrowing of the curriculum arising from the tendency to teach to the examination rather than to the aims of the curriculum; and an undue focus on the attainment of examination results. Attention was also drawn to the problems which arise due to the variation in grading between subjects in the Leaving Certificate. Contributors to the consultation on senior cycle recognised the importance of protecting public confidence in the reliability, objectivity and fairness of the Leaving Certificate examination; however, there was widespread agreement about its limitations as a vehicle of educational assessment. There was criticism of the narrow range of learning assessed; the lack of alignment between the aims and objectives of syllabuses and their assessment; the dominance of assessment of recall and the pressure on learners to perform over a short period of time at the end of senior cycle.

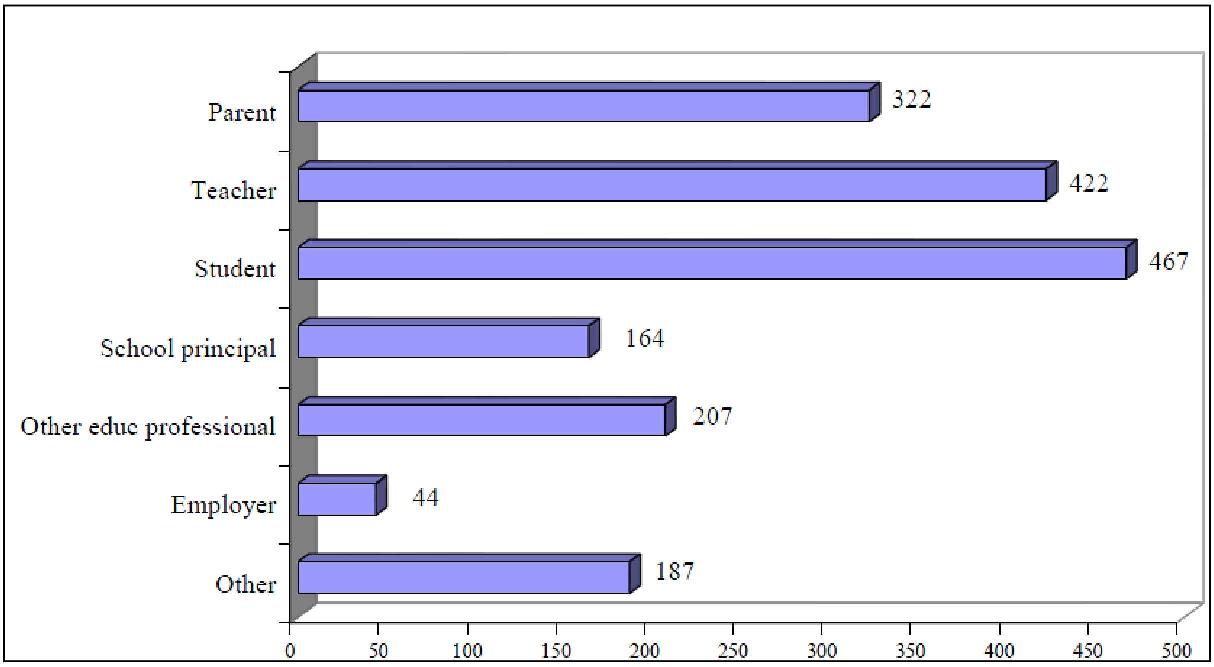

Figure 2-3 Response to the consultation questionnaire by category (NCCA 2003c)

The response to the questions in the consultation questionnaire about the Leaving Certificate as an examination provided some interesting insights into the general perception of the Leaving Certificate from the respondents as shown in Table 2- 5.

The Leaving Certificate Examination	Strongly agree	Agree	Disagree	Strongly disagree
	n= 1,813			
Is a reliable measure of academic ability	15 %	47 %	26 %	12 %
Is a reliable measure of general achievement	7 %	34 %	41 %	18 %
Caters for student with different learning styles	3 %	16 %	50 %	31 %
Provides an appropriate challenge for all students	5 %	27 %	47 %	20 %
Caters effectively for students with special needs	8 %	30 %	39 %	23 %
Is a good predictor of success in higher education	9 %	31 %	42 %	19 %
Is a good predictor of success in the workplace	4 %	16 %	46 %	33 %

Table 2-5 Consultation questionnaire responses on the Leaving Certificate examination (NCCA, 2003a)

The importance of assessment reform and its potential and requirement to effect real change in school culture and curriculum was discussed at the NCCA issues seminar, *Changing Structures in Senior Cycle Education* (Table 2-3). Participants argued that without reform of assessment other suggested changes would have little effect on the student experience of teaching and learning in senior cycle. While assessment within all senior cycle programmes came in for some degree of analysis, many participants identified assessment and certification arrangements in the Leaving Certificate (established) as the areas in greatest need of reform. If the right changes were made, it was suggested, they would "*free up the system*" and contribute to significant improvement in the quality of experience of learners in the senior cycle. Equally, if assessment remained unchanged, it was claimed, *the system will stagnate* (NCCA, 2003a)

2.2.1 The Leaving Certificate as a route to higher education

The dominance of high-stakes assessment is seen as a major impediment to realistic and lasting change in classroom practice, particularly in high stakes summative assessment (Silva, 2009) (Barksdale-Ladd & Thomas, 2000)(Amrein & Berliner 2002) (Wiliam, 2000). Separating assessment and learning leads to a narrowing of teaching and learning as teachers focus on only what is assessed, thus creating

> *… a vicious spiral in which only those aspects of learning that are easily measured are regarded as important, and even these narrow outcomes are not achieved as easily as they could be, or by as many learners, were assessment regarded as an integral part of teaching (Wiliam, 2000)*

In Ireland the influence of assessment on teaching and learning is particularly strong, as the Leaving Certificate is the only criterion on which entrance to higher education is based. Research has shown the effect that the points system has on individual student's subject choices and the backwash effect on teaching and learning. The pressure exerted by examinations even at junior certificate lead to many students taking *grinds* outside of school. Most of the students who do this are middle class, which brings with it the added effect of social inequity (Darmody et al., 2007) (Smyth, 1999). Research carried out as part of the growing up in Ireland series on post-school transitions reported that young people characterised the Leaving Certificate Exam as requiring *too much writing and memory work*. Many students found the need to engage in self-directed work in post –school education as challenging, and felt they had been ill prepared for the kinds of teaching styles they encountered (McCoy et al., 2014).

It is inevitable that, whenever the stakes are high for learner and teachers, and the pressure is on from parents, the manner in which teachers, learners and parents engage with the process of education is affected by their perceptions about what will lead to maximum success in the examination. Much attention is paid to trying to prepare as efficiently as possible to achieve the best examination grades. In interviews with teachers carried out as part of the assessment work with schools (Chapter 6), all of the science teachers interviewed said that they focused extensively on exam preparation for the second half of sixth year, practicing examination questions and leaving out any content that was non-examinable. This behaviour is backed up by studies that show that as the time comes closer to high stakes examinations teachers spent a large proportion of time in exam preparation, narrowing the curriculum and fragmenting knowledge(Emer Smyth & Banks, 2012). The following advice offered to a student on a popular physics website[4] is typical:

> *Q. Do I need to study Mechanics?*
>
> *A. You need to cover all the mandatory experiments in Mechanics (see Section A booklet) and also the short questions in Mechanics if you intend doing Question 5 (see Question 5's booklet), but beyond that you could probably get away with not studying the long questions.*
>
> *I think this is reasonable given that the Mechanics questions can be fairly difficulty, particularly if maths is not your strong point.*

As learners and teachers approach the examination period, the focus shifts more and more on to examination techniques and learning that will be rewarded by high points in the examination (Hyland, 2011). High-stakes testing has become the object rather than the measure of teaching and learning, negatively affecting curriculum, teacher decision making, instruction, student learning, school climate, and student motivation (Gordon & Reese, 1997). Every year, high achieving learners share their *exam-beating* tips and tricks via various media communications.

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[4] http://www.thephysicsteacher.ie/leavingcertphysicsrevision.html

One high achieving learner offered this advice on how to prepare for the Leaving Certificate:

Exam papers, exam papers, exam papers. I even repeated the same questions a few times over the years because the same topics tend to come up again and again, albeit phrased differently. (The Journal.ie Oct 28, 2014)

The Leaving Certificate examinations have been criticised as being predictable, leading to rote learning of large amounts of information by learners, and that the higher order thinking skills are not sufficiently tested. The ESRI[5] research reports, *Choices and Challenges: Moving from Junior Cycle to Senior Cycle Education* (Emer Smyth & Calvert, 2011) and *From Leaving Certificate to Leaving School: A Longitudinal Study of Sixth Year Students* (Calvert, Smyth, & Banks, 2014) reported that the current Leaving Certificate model impacts significantly on teaching and learning in sixth year and earlier years[6]. Key findings from these reports show that:

- The current Leaving Certificate model tends to narrow the range of student learning experiences and to focus both teachers and students on *covering the course*;
- Sixth year students report teacher-centred classes, which focus on practicing previous exam papers, and a very heavy workload;
- Many students contrast what happens in their classes with the kinds of active learning which engage them. Others, especially high-aspiring students, become more instrumental, focusing on what is likely to *come up on the exam paper*, and expressing frustration with teachers who do not focus on exam preparation;
- Almost half of sixth year students take private tuition (grinds) to prepare for the exam;

[5] The Economic and Social Research Institute

[6] https://www.esri.ie/news_events/latest_press_releases/new_studies_of_senior_cyc/

- Young people are acutely aware of the high stakes attached to the Leaving Certificate exam, and the way in which it represents a gateway to future education and job opportunities;
- Levels of stress are high among many Leaving Certificate students, especially among girls. Many are spending considerable amounts of time on homework and study and find it hard to balance the two.

The impact of the transition process from second level to third level on the quality of the learning experience in senior cycle has also been the subject of much debate in recent years. In September 2011 a conference *Transition or Transaction* was held to examine the impact of the transition process on both the quality of the senior cycle experience in schools and on the subsequent capacity of undergraduate students to participate effectively in third-level education. The report, *From Transaction to Transition: outcomes of the Conference on the Transition from Second to Third-Level Education in Ireland* (NCCA/HEA, 2011), and the conference held in September 2011 on which it is based, arose from a joint commitment by the Higher Education Authority and the NCCA to explore how best to improve the quality of the transition from second level to higher education.

As part of the consultation on transition, the Department of Education and Skills hosted a one-day consultation event with 5th and 6th year students to hear their views on the proposals that were made based on the outcomes of the conference. Fifty-six 5th and 6th year students participated in the consultation event. As well as sharing their views on the proposals, the students were asked about their perception of the Leaving Certificate. Students viewed the system as one that is:

- Entirely exam-focused rather than learning or knowledge focused;
- Dominated and driven by a tactical and competitive *points game* and CAO process;
- Imposing rote learning, stunting creative learning and teaching;
- Curriculum-heavy, resulting in time-pressured teaching and cramming and;
- Making the transition from second level to third level a difficult one.

The impact on senior cycle students is obviously adverse, where students have or are:

- Feeling under significant and constant pressure and stress with no time for exercise or a social life to alleviate that stress;
- Discouraged from independent thinking;
- Making subject choices based on what is easier to rote learn;
- Making career choices based on points rather than what they are passionate about;
- Making life-defining decisions at too young an age and pressurised by CAO deadlines (NCCA/HEA, 2013a).

Following the conference, a document was published outlining the next steps *Supporting a Better Transition from Second Level to Higher education: Key Directions and Next Steps* (NCCA/HEA, 2013). The document summarised some of the issues associated with the Leaving Certificate as an examination:

Considered in isolation, the Leaving Certificate, marking the end of second-level education for students, in and of itself need not be a high stakes examination. However, its additional role in selecting students for admission to higher education increases the stakes and, as a result, has negative effects on teaching and learning. It is now generally agreed that the so-called *points race* results from a complex interaction involving

- the nature of preparation for and assessment in the Leaving Certificate Examination;
- the manner in which grades are awarded and converted into a points score to rank students for admission to third level;
- the proliferation of entry routes into higher education; and, the very high demand for a small number of university courses. (NCCA/HEA, 2013b).

There was consensus from the conference that, despite the criticisms, the Leaving Certificate should remain the basis for selection into higher education, rather than developing a separate selection mechanism. Critics of the current model of curriculum and assessment argue that the under-development of critical skills and the narrow range of assessment methods leads to a reductionist approach to learning (NCCA/HEA, 2011). A discussion paper presented at the NCCA/HEA seminar *Entry to Higher Education in Ireland in the 21st Century* (Hyland, 2011), suggested that the current Leaving Certificate curricula of themselves were not the problem, as many syllabus documents require learners to engage critically with subject content and to apply higher order thinking skills. Hyland stated that while the subjects themselves allowed ample opportunity for students to develop higher order thinking skills, it was the Leaving Certificate examination which was the real driver of teaching and learning, and subject textbooks were largely based on the examination. The paper criticised the role of the Leaving Certificate as it is currently used for selection into higher education, as the stakes in the Leaving Certificate are so high that the *backwash effect* on teaching and learning is considerable. The paper highlighted the opportunities for a greater focus on skills through the implementation of the NCCA Key Skills Framework (see Section 2. 3) for the senior cycle, and on the review and development of specifications within which the key skills are embedded

2.2.2 Senior cycle vision and principles

Following the extensive consultation during the early part of the 2000s the NCCA set out its overview of a 'new' senior cycle, informed by a vision of *creative, confident and actively involved young people who are prepared for the future of learning* in *Towards Learning: an overview of Senior Cycle Education*(NCCA, 2009c). The overview set out the values, and the principles that shaped the review and development of senior cycle curriculum and assessment, Figure 2- 4. The document also provided information on the senior cycle curriculum, key skills, assessment and certification, and learning in senior cycle. *Towards learning* provided the direction for the development of the Leaving Certificate science syllabuses as well as the other subjects that were being changed as part of the review.

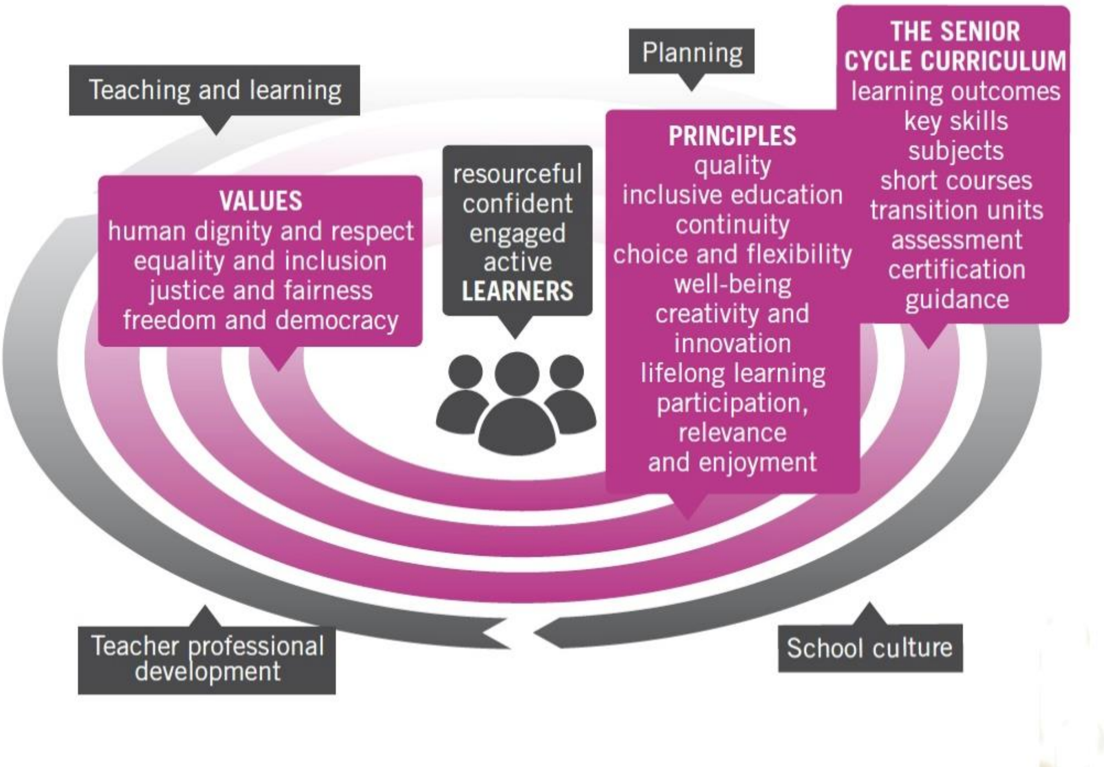

Figure 2-4 Overview of senior cycle

The vision of senior cycle education Figure 2−5 sees the learner at the centre of the educational experience. That experience will enable learners to be resourceful, to be confident, to participate actively in society, and to build an interest in and ability to learn throughout their future lives.

This vision of the learner is underpinned by the values on which senior cycle is based and it is realised through the principles that inform the curriculum as it is experienced by learners in schools.

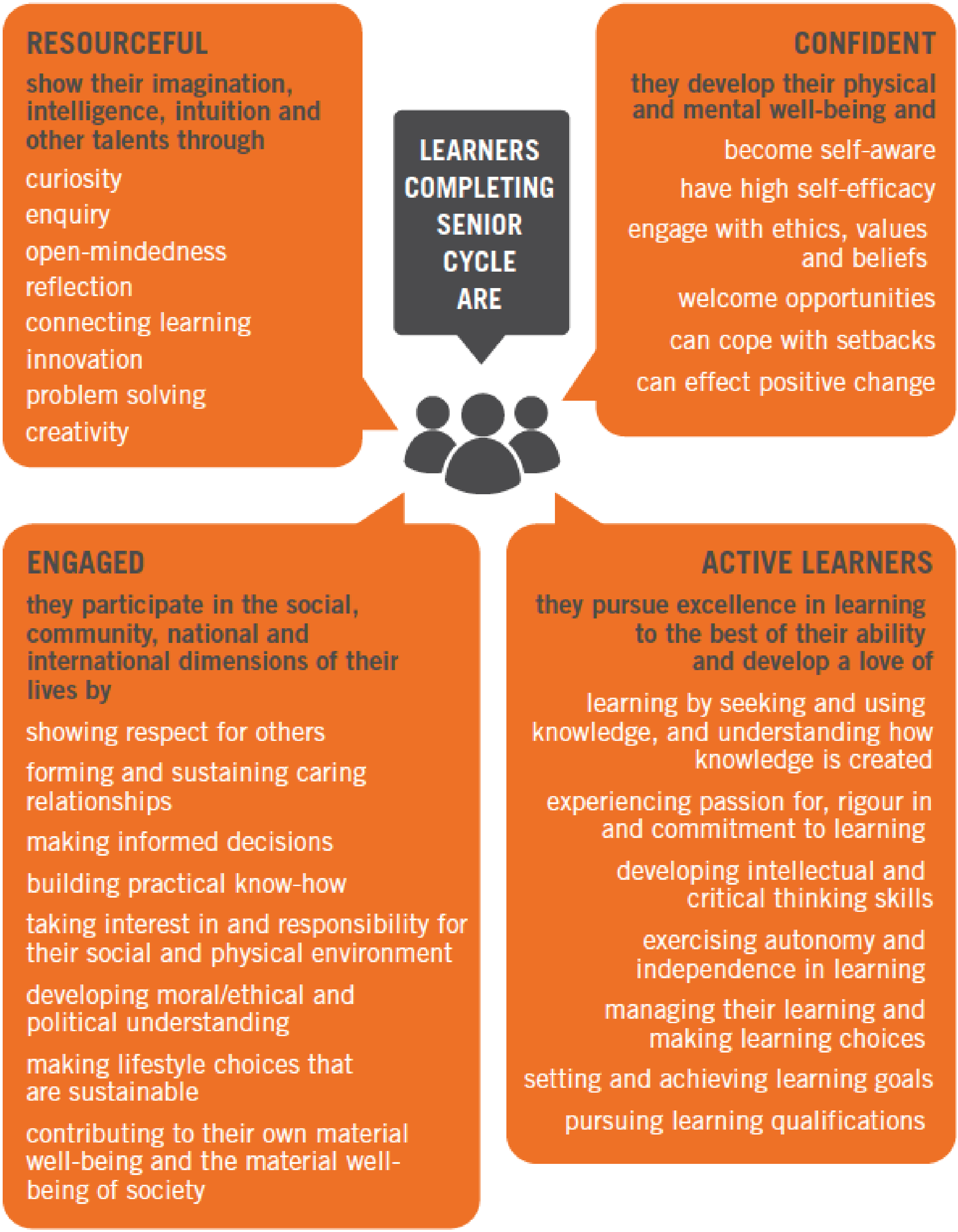

Figure 2-5 Vision of senior cycle

The publication of *Towards Learning* (NCCA, 2009c) gave a clear signal of the progressive changes ahead for senior cycle in Ireland. Subject review would no longer be on a subject-by-subject basis, but would be done in the context of senior cycle program of learning providing a high quality educational experience for all learners. New specifications would enable learners to progress, deepen and apply their learning, and develop the capacity to reflect on their learning. Teaching, learning and assessment methods that interest and motivate students would be developed to support these new specifications:

This vision of the learner is underpinned by the values on which senior cycle is based and it is realised through the principles that inform the curriculum as it is experienced by learners in schools. The curriculum, including subjects and courses, embedded key skills, clearly expressed learning outcomes, and a range of approaches to assessment is the vehicle through which the vision becomes a reality for the learner.

To support senior cycle learners as they develop skills to become *creative, confident and actively involved young people who are prepared for the future of learning*, the NCCA developed a key skills framework for senior cycle.

2.3 Key Skills for senior cycle

2.3.1 Key skills framework

Both of the terms *skills* and *competences* are used internationally, the term *key skills* gained approval in Ireland during the consultation. The consultation on the review, and the international research occurred following the call from the Lisbon European Council for the Member States, the Council and the Commission to establish a European framework defining *the new basic skills* to be provided through lifelong learning. Based on the Lisbon Strategy (2000)[7], the European Framework for Key Competences (2006) presents eight key competences for lifelong learning that all citizens should have for a successful life in a knowledge society[8].

Five key skills were identified as being essential for all senior cycle learners to develop at this stage of their education: information processing, being personally effective, communicating, critical and creative thinking and working with others (figure 2−6). Table 2−6 provides a description of each of the five key skills that were considered essential to

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[7] http://www.europarl.europa.eu/summits/lis1_en.htm

[8] http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32006H0962&from=EN

help learners develop the ability to think critically and creatively, to innovate and adapt to change, to work independently and in a team, and to reflect on their learning. In addition, the skills support mastery of the basic skills of literacy and numeracy, which are crucial for learners to access the curriculum and for their future life chances.

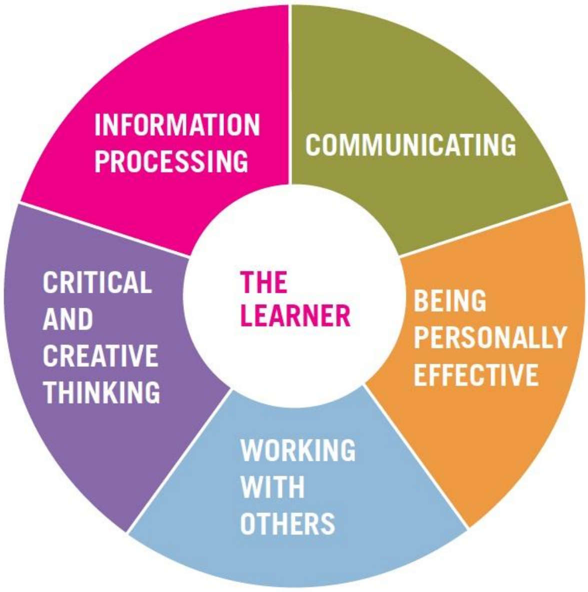

Figure 2-6 Keys Skills for senior cycle

Rather than have a stand-alone key skills module or course, the key skills are embedded in the learning outcomes of subjects. To make the key skills visible within the learning outcomes, a set of generic learning outcomes were established for each skill; these are assessed as part of the Leaving Certificate. The generic learning outcomes are listed in the key skills framework (Appendix 1). Table 2-6 outlines the five key skills.

Skill	Description
Information processing	As well as developing the specific skills of accessing, selecting, evaluating and recording information, learners develop an appreciation of the differences between information and knowledge and the roles that both play in making decisions and judgments.
Being personally effective	As they develop this skill, become more self-aware and use that awareness to develop personal goals and life plans. As well as giving learners specific strategies related to self-appraisal, goal setting and action planning, an important dimension of this key skill is in appreciating how to get things done, how to collect and use resources effectively, and how to act autonomously according to personal identities and personal values.
Communication	Learners develop an appreciation of how central communication is to human relationships of all kinds. As they develop this skill, they become better communicators in both formal and informal situations. As well as developing specific skills in a variety of media they form a deeper understanding of the power of communication—particularly language and images—in the modern world. It also incorporates competence and confidence in literacy as an essential basic skill for all learners.
Critical and creative thinking	Learners develop awareness of different forms and patterns of thinking so that they become more skilled in higher order reasoning and problem solving. In engaging with this key skill, learners reflect critically on the forms of thinking and values that shape their own perceptions, opinions and knowledge.
Working with others	Working with others helps learners to reach both collective and personal goals. It helps learners gain some appreciation of the dynamics of groups and the social skills needed to engage in collaborative work. It contributes to an appreciation that working collectively can help motivation, and capitalise on all the talents in a group. In a broader context, learners come to recognise that working collectively is important for social cohesion and for engaging with diverse cultural, ethnic and religious groups.

Table 2-6 Key Skills for senior cycle

This set of key skills (Figure 2−6 and Table 2−6), and the learning outcomes associated with them, became the NCCA Key Skills Framework (NCCA, 2009a). It was developed to provide a common, unified approach for embedding the key skills of across all future Leaving Certificate specifications. From an Irish perspective these skills were identified as being important for all learners to achieve to the best of their ability, both during their time in school and into the future and in order to fully to participate in society, in family and community life, the world of work and lifelong learning. Embedding the key skills in the specification learning outcomes would open a range of learning experiences for learners, ensure that they were actively involved in their own learning and improve their present and future access to learning, their social interaction, their information and communication abilities and their ability to work collaboratively.

The key skills framework indicates the strong relationships between each of the five skills and their impact on the development of the learner. Each key skill is broken down into essential elements and non-subject specific learning outcomes. The learning outcomes indicate what learners might show as evidence of achievement in the key skill. The development of the senior cycle Key Skills Framework was based on the premise that learners will encounter the key skills frequently and in an integrated way in many areas of the curriculum. They will be developed through the learning outcomes of each subject. Figure 2−7 shows an example of one element of the key skill critical and creative thinking, further broken down into generic learning outcomes. This is further outlined in the Key Skills Framework in Appendix 1

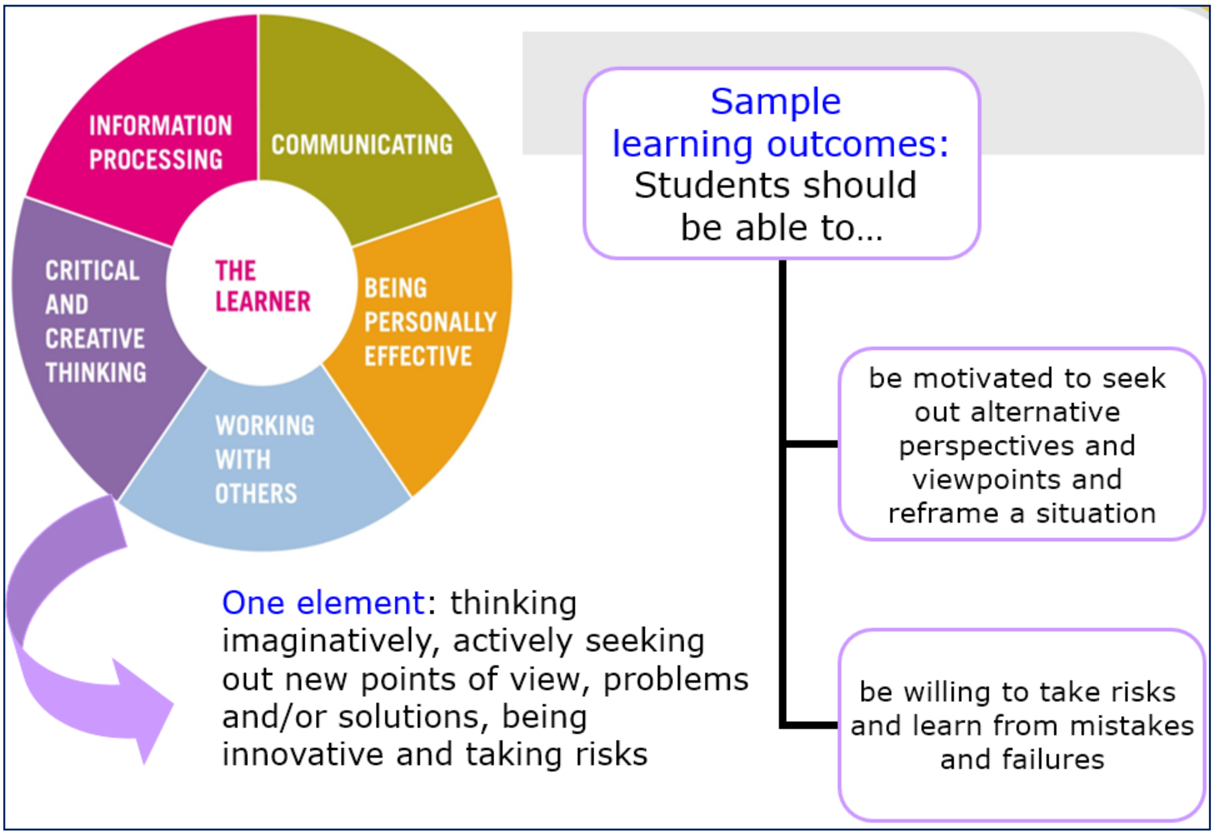

Figure 2-7 Key Skills Framework structure

2.3.2 Key Skills – international context

The development of the Key Skills Framework was informed by the OECD Definition and Selection of Competencies (DeSeCo) Project (OECD, 2005) and the extensive review of 35 thinking and learning skills frameworks by Moseley and his colleagues at the University of Newcastle (Moseley et al., 2004).

21st century skills are currently one of the most ubiquitous phrases in curriculum development discussions. Proponents argue that skills of independent learning, problem solving and collaboration will define the next generation of workers, while critics argue that there is nothing new about these skills, and that overemphasis on skills development detracts from teaching and learning of core content (Silva, 2009)(Young, 2014) . There are a variety of definitions of 21st Century skills, and also many different perspectives on how these skills should be presented in curricula. In an attempt to put a working definition on what constituted 21st century skills in education, a group comprising academics, governments and three major technology companies, Microsoft, Intel and Cisco collaborated on a major research project *Assessment and Teaching of 21st Century Skills* (ATC21S). One of the initial objectives of the collaboration was to conduct an extensive review of the literature of the definitions of 21st century skills developed and used by eleven major organisations, including the Partnership for 21st Century skills (2013) in the United States, and the Lisbon Council (2007) of the European Union. The ATC21S report concluded that 21st Century skills can be grouped into four broad categories: (i) ways of thinking; (ii) ways of working; (iii) tools for working; (iv) skills for living in the world. It further identified ten skills as encapsulating all others and accommodating all approaches (Binkley et al., 2012).

The first two columns of Table 2−7 outlines the categories of 21st Century Skills as grouped by ATC21S and the ten skills associated with these categories. The remaining columns of Table 2−7 maps the skills, identified in Ireland as being essential for all learners to develop as they progress through the education system at each stage of the Irish education continuum, and places them in the context of the ATC21S skills categories.

ATC21S		Stages of Irish Education			
21st Century Skills	Categories	Early childhood themes	Primary priorities	Junior cycle key skills	Senior cycle key skills
Creativity and innovation	**Ways of thinking**			Being creative	
Critical thinking, problem solving decision making		Exploring and thinking	Engage in learning		Critical and creative thinking
Learning to learn, metacognition			Develop learning, thinking and life skills		
Communication	**Ways of working**	Communicating	Communicate well	Communicating	Communicating
Collaboration				Working with others	Working with others
Information literacy including ICT literacy	**Tools for working**			Managing information and thinking	Information processing
Citizenship, local and global	**Living in the world**				
Life and career		Well being	Be well	Staying well	
Personal and social responsibility		Identity and belonging	Have a strong sense of identity	Managing myself	Being personally effective

Table 2-7 Key skills at different stages in Irish education and ACT21S 21st Century skills

From Table 2−7, it is clear that each of the categories defined by ACT21S exists in the senior cycle key skills framework. Of note, ICT literacy is not listed as a separate skill in the Irish framework, but elements associated with ICT are included in the information processing category in Ireland.

Since 2006, developments in curriculum and assessment at senior cycle have focused on the embedding of key skills within learning outcomes and in development of a different approach to assessment in which learners can generate responses that reveal the depth of their understandings and an indication of where they are relative to the knowledge and skills that comprise the learning outcomes. The embedding of key skills requires careful consideration of the balance between knowledge and skills in the curriculum and in learning and of finding appropriate ways of assessing them. This is the basis for discussion in later Chapters.

2.4 The emerging role of schools and teachers in curriculum and assessment development

Working with schools and teachers is a growing feature of the research and development activities of the NCCA. As part of this work, schools and teachers work with the NCCA to trial teaching learning and assessment innovations. In 2009 NCCA published a discussion paper entitled *Leading and Supporting Change in Schools* (NCCA, 2009a). The paper initiated a consultation process about curriculum and assessment developments and their implementation, and the role that the NCCA plays in relation to leading and supporting change in that context. Part of the role of the NCCA was seen as exploring more effective ways of leading and supporting effective change in the classroom by including practitioners in the process of curriculum and assessment development into classrooms. The paper outlined three main areas for discussion:

- Development in curriculum and assessment can be achieved through working both with committees[9] and directly with schools, with the process being informed by research findings and reflections on practice.
- Consultation can be viewed as a continuum from large-scale catch-all consultation to varied, multi-stranded and customised consultation.
- Support for teaching, learning, curriculum planning and curriculum development can go beyond guidelines into the realm of online support and ACTION[10]

Placing teachers at the centre of curriculum and assessment development allows for innovations that require changes in teaching, learning and assessment methods to be trialled in real classrooms, and reflected on in practical settings. In 2006 the NCCA set up a school network that would inform the developments at senior cycle, and set the scene for further curriculum and assessment development work with schools. Three school based initiatives were set up with the school network that would inform future developments and set the scene for future school –based innovations:

- The Key Skills Initiative
- Flexible Learning Profiles
- Transition Unit Development

The Key Skills Initiative is of particular interest to this study, as it involved teachers using action research to develop innovative teaching strategies in order to embed five key skills in teaching and learning in their classrooms. The initiative set out to:

- identify how the key skills can be more consciously and effectively embedded in the teaching of particular subjects, namely Mathematics, Biology, English, Irish, French and Spanish;

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[9] I 2011 the NCCA reclassified its sub-groups as development groups. It also moved away from the term syllabus in favour of the term specification, which embraces both the course, and the means of assessment.

[10] ACTION is an NCCA website that supports teachers in the 'how to' of teaching and learning through sharing real examples of teaching and learning in action.

- explore what kinds of teaching methodologies are most appropriate for the fostering of these skills;
- identify challenges or difficulties encountered in embedding key skills;
- gather evidence from classroom practice to help inform NCCA policy and practice, particularly with regard to the review of subjects and the development of new subjects, short courses and transition units to inform and advise NCCA on the professional development needs of teachers.

What emerged from these early initiatives with schools was a clear signal of the benefits associated with working with practitioners at the site of learning. There were gains for the teacher in terms of professional development and building of support networks and communities of practice. There were significant gains for the system in terms of gaining an understanding of what works well in practice, and just as importantly, what does not work. Teachers listen to other teachers, and the sense of top-down direction is much less when the message comes from a practicing teacher who has tried it out. A significant factor in the school based initiatives is that they are not trials; there is no pre and post testing. The initiatives provide a narrative that can be used to support development and inform practice.

In 2006, new curricula were not yet in place, however, the schools and teachers reported that, even with the current syllabuses, key skills provided a lever for change which impacted positively on teaching and learning. The initiative promoted reflective professional practice and encouraged the sharing of ideas for teaching among teachers. It stimulated innovative approaches by teachers in their teaching and as a consequence, it promoted more engaged forms of learning among learners (NCCA, 2010).

The extent to which school-based curriculum design happens is dependent on whether curricula are centrally devised or whether they are school based. The level of teacher autonomy in curriculum development varies. In Ireland, for example, national curricula are centrally devised, while in the Netherlands a greater degree of freedom operates. Dutch teachers decide within a given context of core attainment targets what content to teach and what methods of teaching they will use. Even in countries where curriculum is centrally devised, teachers may have varying degrees of flexibility in selecting contexts and content. In all cases, teachers have a degree of autonomy around how to teach, what supporting materials to use and the sequence of teaching different areas of the curriculum.

Increasingly, curriculum designers are realising the contributions that practicing teachers can make as co-designers of curriculum materials. Traditionally, curriculum designers have viewed teachers as either transmitters of the intended curriculum or as active implementers of the curriculum materials (Connelly & Ben-peretz, 1997). However, research of learners' experiences of lower second level education has highlighted the critical role learners and teachers can play in identifying successful pedagogical practices and ways to improve learning (Darmody et al., 2007)

During periods of educational reform, teachers must undergo a period of learning as they adapt to change. This learning is contingent on their understanding the nature of the reform and the rationale. One of the benefits of including teachers in curriculum development at any level is the potential to increase capacity, and to facilitate the discussion about, for example, what learning outcomes mean, and what performance they demand of learners. Learning to adapt to change is best done in the teacher's own classroom. When teachers are enabled to use their professional judgement in making decisions about curriculum, teachers and learners are more likely to engage in meaningful conversation with one another, with colleagues and with the wider school community about what works in teaching and learning and why (Elmore, 2006). In a report prepared for the National Institute for Education on education reform in America, the authors take a pessimistic view on the recurring cycles of reform in the American Education system. They comment that reforms dealing with teaching and learning have little or no effect, while those that entrench and solidify school bureaucracy seem to have *strong, enduring and concrete* effects. Whilst policy can set the conditions for effective practice, it can't control how teachers will act in the classroom. Practitioners bring their own knowledge and experience to teaching, but their way is not always consistent with policy and administrative decisions. Long lasting enduring reform, is more likely if the reform decisions include practitioners, administrators and policymakers (Elmore & McLaughlin, 1988).

3 Curriculum development

3.1 Historical review of science education in second level schools

When science was first introduced as a subject as part of the school curriculum in the 19th century, the humanities were firmly entrenched as the educational pursuits that would lead learners to the most noble and worthy outcomes; pursuing studies in science was considered crass and materialistic, and not worthy of the educated classes (G. DeBoer, 1991). Many notable scientists of the time such as Thomas Huxley, Herbert Spence, Michael Faraday, John Tyndall and Charles Elliot campaigned strongly for the introduction of science in schools, arguing that it was essential learning in a world that was increasingly dominated by science and technology, and that study of science provided intellectual training at the highest level (G. E. DeBoer, 2000). These notable scientists also argued that students of science would develop inductive thinking skills by observing the natural world as they carried out independent inquiry and experiments in the laboratory.

During the early years of the 20th century, science education in school was justified because of its increasing relevance to contemporary life. Notable amongst the writers about scientific literacy was John Dewey (1859-1952), an American visionary in education, pedagogy, psychology, and social reform. At the turn of the 20th century, Dewey wrote,

> *The future of our civilization depends upon the widening spread and the deepening hold of the scientific habit of mind; and that the problem of problems in our education is therefore to discover how to mature and make effective this scientific habit,(Dewey, 1910).*

By the 1930s, many felt that too much focus had been placed on the relevance of science to everyday life, and that curriculum developers should return to teaching the fundamental principles of science. Figure 3−1 shows key influences on the development of science education in second level schools.

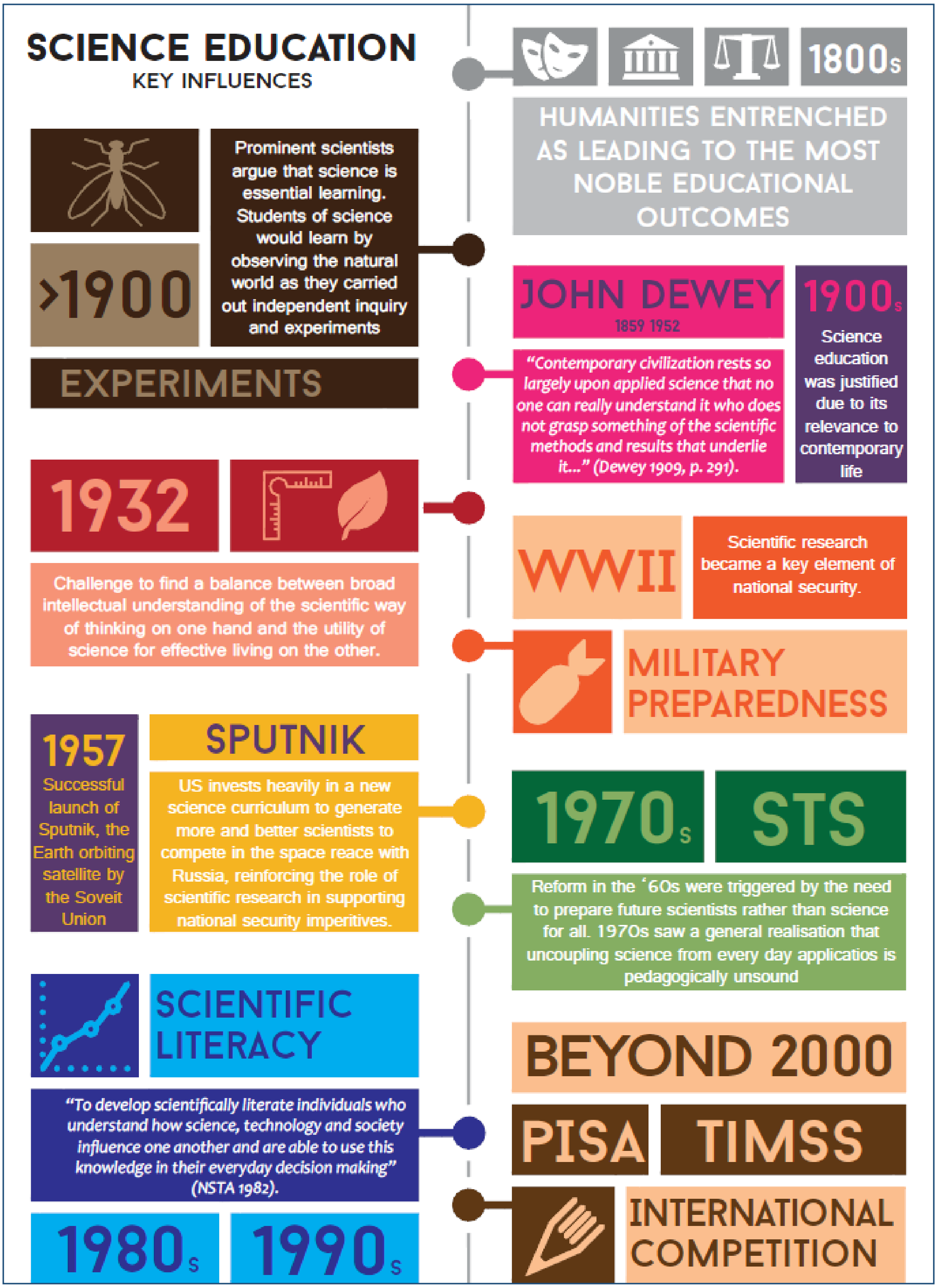

Figure 3-1 Key influences on the development of science education in second level education

Throughout the 20th Century and into the 21st Century, the rationale for teaching science in schools has continued to reflect economic and social changes. World War II focused the attention of many countries on the need for military preparedness; hence, scientific research became a key element for national security. The strategic role of scientific knowledge in society was becoming increasingly important. Following the successful launch of Sputnik by the Soviet Union in 1957, the US government invested heavily in a new science curriculum in an effort 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. This rationale for investment was unpopular with neo-liberalists, who were not comfortable with science education being justified on the basis of national security concerns. As the decades passed, the attention to science never waned but the *reasons for anxiety about the quality of science education expanded* (Atkin & Black 2003). Quality science education was viewed as having the potential to improve the economy, protect the environment, and improve learners' preparation for employment as well as preparing learners to become scientifically informed citizens. The result of this was science curricula that were designed by scientists for future scientists, where few links were made between the lives of learners and the science they were studying.

The term *scientific literacy* first came into the education vocabulary in the 1950s, arising out of concerns that the general public did not have sufficient understanding of science. The discussions on scientific literacy turned into a debate about the purpose of compulsory science. An argument was put forward that compulsory science had too strong an academic orientation and did not prepare learners for life; the overly academic emphasis of science education was unreasonable as only a small proportion of learners actually went on to study science at a Higher level. Initially, this debate did not gain much attention; educational reforms in the 1960s were triggered by the need for preparing future scientists, rather than considering the needs of all learners. By the 1970s there was a general realisation that the uncoupling of science from its everyday applications was pedagogically unsound, and a growing recognition of the importance of science in a social context emerged. A new body of science education thinking emerged that became known as the STS (science-technology-society) movement. The proponents of the STS movement argued that science should be taught in relation to the personal needs of the learners and in relation to important aspects of the contemporary society, rather than as primarily a preparation for university studies. The argument had a clear democratic orientation, highlighting the need of citizens to be able to identify, analyse and engage in science-related social issues. 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).

In the late 1980s and early 1990s another movement started in the US parallel to the scientific literacy movement called the *standard reform*; it was motivated by globalisation and the need for the U.S. to compete for the highest level of educational achievement. The standard reform movement was triggered by the publication in 1983 of *A Nation at Risk: The Imperative for Educational Reform*, report by American President Ronald Reagan's National Commission on Excellence in Education (NRC, 1983). Its publication is considered a landmark event in modern American educational history. The most famous line of the widely publicised report declared that "*the educational foundations of our society are presently being eroded by a rising tide of mediocrity that threatens our very future as a Nation and a people*" (NRC, 1983). Among other things, the report contributed to the ever-growing sense that American schools were failing, and it initiated a wave of local, state, and federal reform efforts. The report recommended that schools should adopt more "*rigorous and measurable standards*". It used evidence from falling Standard Achievement Tests (SATs) and international school data to argue that academic standards had fallen in mathematics and science in the U.S., and claimed that this had caused the declining economic position of the U.S. in the world market. One would have expected that this would have worked against scientific literacy and moved the focus back to a traditional academic-oriented curriculum, but that did not happen. Instead, the two movements merged into a common focus on clarifying what learners should learn in science education and what *level* their achievement should have. A further document in the US, *Science For All Americans* (American Association for the Advancement of Science, 1989)[11] had a strong influence on the first National Science Education Standard (NRC, 1996). The standards document attempted a compromise between scientific literacy and an academic oriented science by stating that *to keep pace in global markets, the United States needs to have an equally capable citizenry*. The report articulated the view that an understanding of the nature of science, technology and mathematics is essential for all citizens in a scientifically literate society.

In recent decades, the need to encourage scientific literacy has also been seen as a crucial component of science education at second level. During the late 1980s and into the 1990s many science education researchers began to see scientific literacy as the leading idea of a new curriculum reform movement. *Beyond 2000: Science education for the future* (Millar & Osbourne 1998) was published in 1998. This seminal document reported the collective vision of over 20 leading science education experts about science education into the new millennium. The report emphasised the growing importance of scientific issues in the daily lives of young people and the need for young people to have sufficient knowledge and understanding to follow scientific debates with interest.

A prominent feature of the National Science Education Standards (NRC, 1996) was a focus on inquiry. The term "inquiry" is used in two different ways in the Standards. First, it refers to the abilities learners should develop to be able to design and conduct scientific investigations and to the understandings they should gain about the nature of scientific inquiry. Second, it refers to the teaching and learning strategies that enable scientific concepts to be mastered through investigations. In this way, the Standards draw connections between learning science, learning to do science, and learning about science. In 2000 *Inquiry and the National Science Education Standards: A Guide for Teaching and Learning* was published as a practical guide for teachers, professional developers, and administrators to enable them to respond to the Standards' call for an increased emphasis on inquiry (NRC, 2000). In the US science education in the various states was informed by the National Science Education Standards (NRC, 1996) and Benchmarks for Science

[11] http://www.project2061.org/publications/sfaa/online/chap1.htm

Literacy from the American Association for the Advancement of Science (AAAS) to guide the development of their curricula. In 2013 these two documents were replaced by The Next Generation Science Standards (NGSS) (NRC 2013).

Inquiry Based Science Education was also gaining prominence in Europe. In 2007 a key European Commission publication entitled *Science Education Now: A Renewed Pedagogy for the Future of Europe* presented recommendations for actions to promote inquiry and stimulate inquiry-based learning among young people (Rocard et al., 2007). Amongst its recommendations was the introduction of inquiry-based approaches in schools, and training of teachers in inquiry-based science education. Following the Rocard report, the 7th Framework Programme (FP7) funded European research and technological development from 2007 until 2013. As part of FP7, many cross European initiatives, focussed on promoting inquiry, were established to promote inquiry based learning. Ireland participated in the ESTABLISH[12] PATHWAY[13], SAILS[14], and FIBONACCI[15] projects, all of which were based around aspects of inquiry based science education (IBSE).

International testing of science and mathematics through programs such as the Program for International Student Assessment (PISA) and Trends in Mathematics and Science Studies (TIMSS) has been a key influence on science education policy. TIMSS and PISA compare student achievements internationally in science and mathematics. TIMSS was first conducted in 1995 at five grade levels (the third, fourth, seventh, and eighth grades, and the final year of secondary school) in more than 40 countries. As well as student achievement TIMSS reports on mathematics and science curricula of the participating countries through an analysis of curriculum guides, textbooks, and other curricular materials. TIMSS results were released in 1996 and 1997 in a series of reports, providing

[12] http://www.establish-fp7.eu/

[13] http://www.pathway-project.eu/

[14] http://www.sails-project.eu/portal/

[15] http://www.fibonacci-project.eu/

valuable information about mathematics and science instruction to policy makers and practitioners in the participating countries.

PISA was first introduced in 2000 to compare education policies and outcomes of participating economies, and to date, students representing more than 70 economies have participated in the assessment. PISA tests are designed to assess competency in science, mathematics, and reading literacy at the end of compulsory education. As well as data from the assessment, PISA collects information through background questionnaires which provides context for the interpretation of the results. The influence that PISA has on policy is contributed to by the extensive media coverage it receives, particularly when results are published. The results generate public discussions about education reform and performance. Different types of national reactions to PISA results have been identified in the literature (Grek, 2009). Some countries experienced *PISA-surprise*; for example, the Finnish were pleasantly surprised by their success in the assessment, and by the international interest in their education system that resulted. In some countries the results create national consternation, described by Grek as *PISA-shock*. For example this occurred in Ireland following the PISA 2009 results when Ireland performed below expectations. An OECD working paper reported on an investigation into how, and the extent to which, countries use PISA in policies and practices, to evaluate and improve school-system performance (Breakspear, 2012). The report notes that reactions vary on the basis of differences between expected and actual test outcomes (higher than expected, lower than expected, consistent with expectations). For example in New Zealand, students' high performance level in the test reinforced existing positive feelings about recent reforms, while in the United States, the below average results achieved by students were also consistent with expectations. In both cases, no new reforms were proposed. What is evident is that PISA has become accepted as a reliable instrument for benchmarking student performance worldwide, and that PISA results have had significant influence on policy reform in the majority of participating countries/economies.

More recently, the epistemic nature of science, the ability to interpret and critique scientific evidence/data while understanding the scope and limitation of scientific knowledge, has also emerged as an important component of science education.

Throughout the 2000s ongoing research has added to the knowledge of the way students learn science. Research into cognitive and developmental sciences provides a body of knowledge on how learners learn. This research has shown that learners bring preconceptions to the classroom about how the world works, their competence in science requires factual knowledge and conceptual understanding for them to make sense of how the world works. Also evident is that learners can learn to control their own learning through metacognitive strategies(Donovan & Bransford, 2005). The report *Taking Science to Schoo*l (Shouse et al., 2007) brings together research literatures from cognitive and developmental psychology, science education, and the history and philosophy of science to synthesise what is known about how children learn the ideas and practice of science. Most striking from this report is the evidence presented about childrens' intellectual capability to learn science; they come to school with the cognitive capacity to engage in serious ways with the enterprise of science; as educators, we sometimes underestimate what young children are capable of, and may set the bar too low. The report describes four proficiencies that link the content and practices of science. Students who are proficient in science:

- know, use, and interpret scientific explanations of the natural world;
- generate and evaluate scientific evidence and explanations;
- understand the nature and development of scientific knowledge; and
- participate productively in scientific practices and discourse (Shouse et al., 2007)

This understanding of how children learn and the realisation that discipline knowledge, competencies and values all contribute to a fulfilling science education has led to the development of *new curricula for the 21st century* that will be described in a further section.

3.1.1 Development of the role of practical work in second level schools

It is interesting to chart how thinking on the role of practical work in second level schools has developed in parallel with changing ideas about science education. Over the years, there has been little argument that practical work constitutes an important element in school science, and the development of practical skills is acknowledged as an important outcome of science education (Reiss, Abrahams, & Sharpe, 2012),(Abrahams & Millar, 2008). What is notable is the change over the years of the relationship between practical work and conceptual understanding of science. In 1811, Maria Edgeworth, an Irish female pioneer of science education co-authored a two-volume work, *Essays on Practical Education* with her father that educational historians refer to as a seminal and progressive work in the 19th century because of its support of scientific inquiry (Scantlebury & Murphy, 2009). Modern critiques of science education call for emphasising the relevance of science content to the learner, making science learning interesting and enjoyable for children, and providing opportunities for experimentation and yet the Edgeworths voiced the same ideas almost 200 years ago:

> *The great difficulty that has been found in attempts to instruct children in science has, we apprehend, arisen from the theoretic manner in which preceptors have proceeded. The knowledge that cannot be immediately applied is quickly forgotten and nothing but disgust connected with useless labour remains in the pupil's mind . . . (Pupils) senses should be exercised in experiments, and these experiments should be simple, distinct and applicable to some object in which the pupils are immediately interested. We are not solicitous about the quantity of knowledge that is obtained at any given age, but we are extremely anxious that the desire to learn should continuously increase . . . Until children have acquired some knowledge of effects, they cannot inquire into causes.*
>
> *Observation must precede reasoning; and as judgement is nothing more than a perception of the results of comparison, we should never urge our pupils to judge until they have acquired some portion of experience (Edgeworth and Edgeworth 1811, cited in Scantlebury & Murphy 2009)*

At that time, the primary purpose for the limited amount of scientific experimentation in schools was to verify previously taught scientific ideas. In the early years of the 20th century, practical work began to be seen as an important element in facilitating a discovery based approach to science. In 1903 Armstrong wrote about the necessity for learners to develop manual dexterity and psychomotor skills, so that they could manipulate apparatus and engage in the practical applications of science education:

> *The power of devising, and fitting up apparatus, as well as devising and carrying out experiments is cultivated. Thus handiness is acquired (Armstrong, 1903)*

Various influential reports followed that changed the focus of practical science education in schools between supporting conceptual understanding on one hand, and developing *hands-on* transferable skills on the other. The influential *Thomson Repor*t (Thomson, 1918) justified practical work in school science on the basis of developing conceptual understanding; and the equally influential *Norwood report* (Norwood, 1943) advocated practical work for the development of practical skills that would be transferrable to the world of work in an increasingly industrial workplace. At this time, influenced by Brunner and others, discovery based learning enjoyed a resurgence. By the late 1960s pioneering work by Brunner gave rise to the Nuffield discovery based learning course. The intention of the Nuffield courses was to encourage learners to discover science for themselves (Nuffield Foundation, 1966). However, the recipe type package that accompanied the program distorted the discovery model of the *student as a scientist* model, and the Nuffield approach was short lived. At the same time, there was growing concern that, in the over-emphasis on discovery-based learning, the shift away from conceptual understanding of science had gone too far. There were concerns that science courses were being taught which were practically devoid of science content. Driver amongst others argued that *doing* did not necessarily lead to understanding. Driver famously changed the much used saying *I do and I understand* to *I do and I am even more confused* (Driver, 1983).

Developments in technology have changed what is possible in school laboratories, and will potentially change what happens there; but what will remain of prime importance is why it happens, and how the interaction with equipment and experimentation and investigation enhances science education. Current developments in practical work will be discussed in more detail later.

3.1.2 Emerging themes

Over the past decades there have been many changes in emphases in science education, both in the theoretical frameworks and in the relationship between practical work and those frameworks. What has emerged is a realisation that the essential elements of science education in second level schools include a balance between facts and discovery, and between *hands on* and *minds on*. In an effort to define what those elements are, a Delphi study of the expert community brought together 23 experts, drawn from leading and acknowledged science educators; scientists; historians, philosophers and sociologists of science; experts engaged in work to improve the public understanding of science and expert science teachers (Osborne, Ratcliffe, Collins, Millar, & Duschl, 2002). The outcome of the research was a set of nine themes encapsulating key ideas 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 & Olson, 1998). Table 3−1 compares the themes emerging from the Delphi study with the most prevalent ideas (ideas found in six or more national curriculum documents) on 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.

These *essential elements* that are referred to in Table 3−1 are evident in the more recently revised curricula. There are those who question the extent of recent revisions to curricula and argue that increase in curriculum reform globally is partly in response to globalization, economic competitiveness and citizenship (Yates & Young, 2010).

Themes in McComas & Olson.	Themes in Osborne et al.
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
	Diversity of scientific thinking
Changes in science occur gradually	
Science has global implications	
New knowledge must be reported	

Table 3-1 Comparison of the themes emerging from McComas & Olson (1998) and Osborne et al. (2002)

Common to *new curricula* is their articulation of content in terms of assessable outcomes, set out by subject area. While outcomes tend to be less prescriptive in terms of content they are still framed as assessment standards, which has implications for assessment. The comparative lack of specification of outcomes based curricula have laid them open to criticism that knowledge has, in some way, been downgraded and stripped from the curriculum (Young, 2014) (Priestley & Sinnema, 2014). Critics argue that reforms based on economic imperatives for the development of soft skills required for the work are at the expense of core disciplinary knowledge.

3.2 Development of outcomes based education

Curriculum theory arose, initially in the United States in the early part of the 20th century, to solve problems faced by school principals of perceived poor teaching, lack of standards and lack of social cohesion in school curricula. These problems were partly due to America's involvement of world war one, and the ban on immigration between 1915 and 1920. Early curriculum theorists, such as Joseph Rice, Franklin Bobbitt and Ellwood Cubberly, claimed that the American schooling system was in a poor state and lacked accountability and standards. Rice introduced a solution in which expected student objectives were stated at the outset, and teachers were measured on the extent to which learners achieved those objectives (Lee, 2003). The early proponents of instructional objectives advocated that the goal of schools was to deliver a prescribed set of facts and that those facts were not disputed. In his book *Preparing instructional objectives* Robert Mager defined a learning objective as an intended *result* of instruction, rather than the *process* of instruction itself (Mager 1984).

Confident that the lessons from manufacturing could be successfully applied to schools, Bobbit applied a management strategy called Scientific Management, to education. It became known as *Taylorism* after the developer of the theory, Frederick W. Taylor, an American engineer. Taylorism was a factory management system developed in the late 19th century to increase efficiency by evaluating every step in a manufacturing process and breaking down production into specialized repetitive tasks. This system was adopted by curriculum developers in an attempt to maximise the efficiency of the curriculum, by providing set instruction and efficient organisation of teaching resources. There was top down control of what was taught, how it was taught and how it was measured. Educational objectives that outlined the content and procedures of instruction were developed as tools in the design, implementation and evaluation of an instructional program. The instructional process itself was managed, as was the means of finding out if the instruction was effective (Mager, 1984). Mager argued that a meaningful stated objective is one that succeeds in communicating the designer's intent; i.e. what should the learner be able to do? Under what conditions do you want the learner to be able to do it? How well must it be done? This level of control resulted in what was referred to as *the teacher proof curriculum*. The curricular content was pre-determined elsewhere, and atomised to such an extent that knowledge was transmitted in small unrelated bits.

By the end of the 70s, influenced by Dewey, the narrowness of the behavioural objectives approach started to be questioned (W. F. Pinar, 1978),(Apple, 1978). Apple was influential at the time as he helped to put the political purposes into perspective. He argued that the curriculum was not just a neutral assembly of knowledge to be put into classrooms; rather it was a selection of what is appropriate, acceptable, legitimate knowledge. It was recognised that the key to improving curricula lay in the culture that it engendered rather than in the ticking off of clear and achievable goals (Purkey & Smith, 1983). In 1975 Stenhouse wrote one of the most influential books on curriculum design, in it he defined curriculum as

> *… an attempt to communicate the essential principles and features of an educational proposal in such a form that it is open to critical scrutiny and capable of effective translation into practice (Stenhouse, 1975).*

Towards the end of the 1980s William Spady expressed education in terms of student outcomes. This was a very different approach from his colleagues who viewed student success only in terms of test scores. Spady was concerned about the educentric education system in the US, a system that was driven by *what was and always has been* rather than *what could and should be* (Killen, 1999). At the same time, there were general concerns that the education system was not equipping learners with the necessary competences and knowledge for further learning or for the world of work. Spady proposed that success should be measured in terms of outcomes, *high quality, culminating demonstrations of significant learning in context* (Spady, 1994). He said that success should be measured in terms of *things that learners could demonstrate beyond school*, rather than by an accumulation or average of things that could be demonstrated during their educational experiences, and that their achievement be measured in outputs such as what they were able to do rather than inputs based on the course credits that they had earned or the hours they had spent in class.

In the 1990s a number of agencies in the U.S., including the National Academy of Sciences, the U.S. Department of Labour and the New Standards Project, developed various types of educational outcomes that were content-specific or integrated several subject areas. Some states and districts mandated outcomes, while others presented them as guidelines. Other states encouraged districts and schools to develop and adopt their own outcomes, based on a particular model put forward by the state. In reality, many educators could not deal with such complexity and turned to item banks of pre-written statements (Bohlinger, 2012). The same objection that was given to objectives in the 1960s was applied to outcomes in the 1970s, through a rejection of the *straight-jacket* imposed by curriculum designers and the re-emergence of non-behavioural objectives, such as understanding concepts and appreciating art forms (Souto-Otero, 2012). Eisner and other leading figures in this movement did not reject the notion of learning outcomes (Eisner, 1979). In fact, they embraced it, because it helped them to reject the limits imposed by a narrow focus on educational objectives, which they argued are always less complex and numerous than the outcomes educational experiences can produce. What Eisner rejected was the notion that the precise dimensions of such outcomes could be specified to the level of clarity rationalists argued for.

In the early 2000s, further education reform in the US was based on the premise that setting high standards and establishing measurable goals can improve individual outcomes in schools, and promote inclusiveness and equal access. The No Child Left Behind Act (NCLB, 2003), which introduced the Core Common Standards, was introduced in 2001. The core goals of outcomes based education are evident in the Core Common Standards, in that they have been developed to be:

- Fewer, clearer, and higher, to best drive effective policy and practice;
- Aligned with college and work expectations, so that all students are prepared for success upon graduating from high school;
- Inclusive of rigorous content and applications of knowledge through higher-order skills, so that all students are prepared for the 21st century;
- Internationally benchmarked, so that all students are prepared for succeeding in our global economy and society; and research and evidence based (NRC, 2012).

The core standards are developed for English, humanities and mathematics. The science standards, called the Next Generation Science Standards (NGSS) were developed separately, and followed on the core standards. The NGSS were developed based on the premise that there are three dimensions pertinent to *being a scientist*. Learners need knowledge and understanding of science facts and concepts, they need to be able to exhibit scientific practices, i.e. work and behave like a scientist, and to be able to organise interrelating knowledge and practice from various science fields into a coherent and scientifically-based view of the world (NGSS, 2013)

3.2.1 Learning outcomes: a critique

There are ongoing arguments about the value of learning outcomes (Donnelly, 2007). Critics maintain that defining learning in terms of outcomes is *conceptually flawed, difficult to implement and downgrades knowledge* (Priestley & Sinnema, 2014). The argument in favour of defining learning in terms of outcomes is that the focus is on learning being an enabling process that helps learners acquire knowledge as they develop capabilities and attributes. In this way learning outcomes exert a pull rather than a push on the teaching and learning process (Tunstall & Maxwell, 2001) (Maxwell, 2002), (Fensham, 2002). The result of a learning outcomes approach is that planning for teaching and learning happens concurrently with planning for assessment. Whilst learning outcomes may be broad, their achievement must be capable of being measured in some way. *Assessment of Significant Learning Outcomes*, a project carried out by Richard Daugherty, Paul Black, and their colleagues for the Teaching and Learning Research Programme (TLRP) of the Social and Economic Research Council looked at alternative perspectives on learning outcomes and the challenges that their assessment posed(Daugherty et al. 2012). The project had its origin in the debates about the outcomes that are assessed, and the programs that those outcomes relate to. The evidence from the project was that it is too simplistic to imagine explicit outcomes of assessment being in some way aligned with a pre-specified curriculum. Instead, it proposed a multi-layered process of knowledge being constructed with numerous influences at work at every level from the national system to the individual learner:

Rather than thinking in terms of aligning assessment more closely to curriculum, the construction of learning outcomes is better understood as a *complex, non-linear* *interacting system with the with the ultimate goal being a synergy that embraces curriculum, pedagogy and assessment* (Daugherty et al., 2012).

Tunstall and Maxwell argue that there are two caveats for learning outcomes to achieve the synergy that Daugherty and his colleagues mention. First, that learning outcomes need to be sufficient as well as necessary, and second, that they need to be adequate for making appropriate distinctions between those students who have and have not achieved those learning outcomes (Tunstall & Maxwell, 2001).

To be effective, learning outcomes should

enable learners to:	be clear about what they are meant to be learning monitor their own progress be able to take greater control over their own learning
enable parents to:	understand how learning aligns with the aim and objectives of the specification understand how assessment will reward the development of deep learning and skills the place of school education in the development of the learner beyond school
enable teachers to:	improve assessment methods by enabling assessment techniques to be matched to the intended learning outcomes thereby ensuring more authentic assessment provide more focused feedback to learners select what to teach and the best order in which to teach it choose the most appropriate teaching methods and learning tasks
enable assessors to:	provide assessments for certification that are closely related to the learning envisaged in the aims of the specification achieve assessment validity in that it measures what the curriculum sets out to teach devise ways of validly and reliably assessing so-called "higher-order" processes

Table 3-2 Learning outcomes as enablers

The challenge for curriculum designers is to craft well-defined learning outcomes based on key knowledge and concepts that lead to learning processes which are focused on deep learning of a limited set of fundamental concepts, and to have valid assessment processes which have beneficial effect on teaching and learning and that act as enablers as shown in Table 3−2.

The construction of learning outcomes, therefore, is a far more complex procedure than it might first appear. Learning outcomes should be considered as a process rather than a product. If the construction of learning outcomes is a complex non-linear interacting system, then an organising framework is needed that can act as a scaffold for their construction. The organising framework can then be used as the lens through which teachers, learners, parents, and assessors interpret the curriculum and see the relationship between curriculum pedagogy and assessment.

3.2.2 Insights into the complexities involved in switching to an outcomes-based curriculum.

During the early to mid-90s, all Australian states and territories, to some degree, adopted an outcomes-based education approach to school curriculum based on a developmental and constructivist philosophy of education. In guiding learners towards outcomes, teachers were to facilitate learners, and dispositions and attitudes would take priority over received knowledge (Donnelly, 2007).

Research carried out on a cluster of schools in rural Queensland sought to establish a connection between successful implementation of an outcomes based education (OBE) curriculum and an understanding of the curriculum's intended constructivist learning theory and pedagogy (Cooper 2007). In the study, specific factors which resisted curricular reform were identified. These factors included school culture, awareness and understanding of constructivist learning theory and associated pedagogy.

Resistance to curriculum reform was quite dramatic, with 54% of the sample population preferring not to implement outcomes syllabuses if given the choice (Figure 3−2). There was no significant difference between teacher and administrator populations in those who preferred not to implement outcomes based education. Being supported in curricular reform was viewed as important to effectively understanding outcomes based education by teachers (61%) and administrators (62.5%). Teachers were equally divided on whether none/limited or sufficient/ample time had been offered to develop such an understanding. Administrators were more decisive, with 87.5% believing that limited time was devoted to developing outcomes based education understanding in their school.

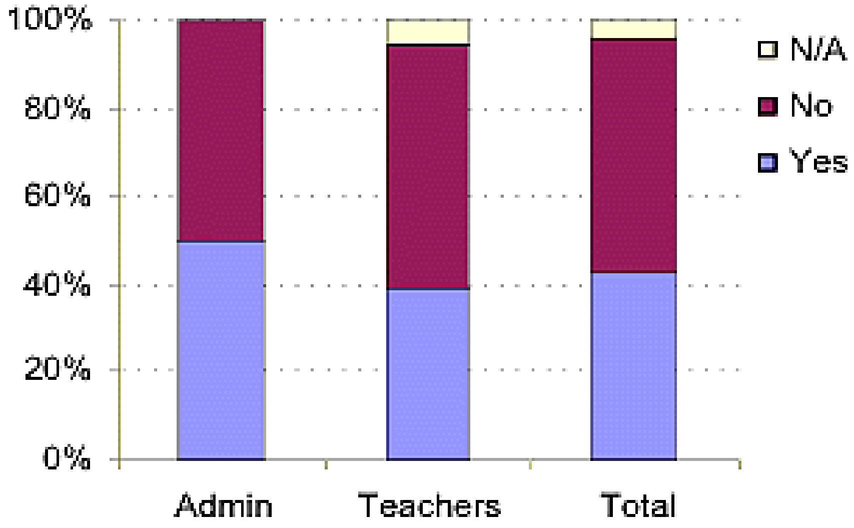

Figure 3-2 Administrator and teacher preference for OBE (from Cooper, 2007)

Cooper's research indicates that current knowledge of stakeholders should be established before implementing curriculum reform, and that teachers should be provided with evidence for the need for reform. The resistance to outcomes based education evident in this study demonstrated that the Queensland Studies Authority's (QSA) professional development plan had been unable to apply the learning theory it wished teachers to take into the classroom. The study concluded that although schools were offered in-service professional development to implement an outcomes curriculum, they were given insufficient training in the pedagogy necessary to align the curriculum with student learning and appropriate assessment.

The study also highlighted the importance of appropriate forms of communication about educational reform. Although constructivism was a defining feature of the QSA's outcomes based syllabuses, 47.5% of teachers sampled did not know what the word meant. Although 68.5% of teachers were able to select one of two preferred definitions of productive pedagogies from a choice of four, the researchers argued that there was evidence from practice that teachers continued to do *what works for them*, without understanding the theoretical rationale for the adoption of and outcomes based approach to education. 81% of the teachers involved in the study went on to indicate that *some* or *a lot* of understanding of constructivism would affect their school's curriculum reform process. The sample population (89%) overwhelmingly believed that *none* to *limited* time had been spent on the professional development of constructivism (Cooper, 2007).

Curriculum development internationally was also undergoing change in response to changing ideas about what curricula would best serve young people in second level education. Following extensive review of the literature, Cheung & Ng (2000) developed a useful overview of curriculum orientation (Table 3−3) which provides a nice snapshot of how curriculum change has emerged over the years. In reality, curricula are not strictly of one type or another, but they encompass features of all three. The three types of second level curricula are presented here in terms of science curricula, but the curriculum orientation could be applied to any subject.

Curriculum orientation	Curriculum intent	Curriculum content	Teaching learning strategy	Assessment
Academic curriculum ***Science is discipline knowledge***	Understand science subject matter. Prepare students for advanced study of science. Focus on cognitive learning objectives	Factual and theoretical knowledge that reflects the structure of a science discipline such as chemistry biology and physics	Didactic. Students listen to teacher talk, read text, memorise laws and formulae, answer factual questions, watch demonstrations, and practice laboratory skills	Students mastery of scientific knowledge
Processes Curriculum ***Science Is a process of inquiry***	Teach students how to learn science. Develop essential inquiry skills	Scientific methods. Science process skills such as observing, hypothesising, and measuring. General inquiry processes such as problem solving, use of evidence, and analytical reasoning	Laboratory-centred, experimental process approach. Investigations and simulated research activities. Students learn scientific concepts by discovery	Students' acquisition of science process skills. Correct use of scientific methods
Society-centred Curriculum ***Science is a tool for improving our society***	Prepare students to utilise science for improving their own lives and for coping with an increasingly technological world. Understand the human nature of science. Integration of affective, cognitive and psychomotor objectives.	Science-based real-world contemporary societal Issues. Emphasise applications of science to societal problems, environmental concepts, ethics, values, decision-making, multidisciplinary studies, and careers in scientific fields.	Student-centred. Classroom as a joyful and facilitating environment. A constructivist view of learning. Contextual learning and storyline approach. Reports.	Students' abilities to apply scientific knowledge to the complex technological aspects of everyday life. Competence in handling Information technology.

Table 3-3 Orientations to second level science curricula (Cheung & Ng 2000)

The three models shown in Table 3−3, are not the only models of curriculum that exist; they represent the major curriculum philosophies of the past decades. Although the table does not represent a timeline of curriculum development, the focus in curricula has shifted away from the academic model, towards the processes, and society centred model, where the learning is student centred, and knowledge is applied to students own experiences. In reality, these divisions are artificial. Most recently developed curricula have retained aspects of all of these models. Discipline knowledge is learned through a process of inquiry, where appropriate, and topics that are relevant and have societal importance provides context.

Table 3−3 highlights the different emphases of curricula which go in and out of fashion; for some the pace of change is difficult to sustain. Digital media and technology are playing key roles in shaping education, and will continue to do so into the future. Students have an unprecedented access to information, and need to develop strategies to use that information in the best way that they can. Technology enables instant connection and collaboration on a global scale. With a renewed emphasis on developing skills of communication, argumentation is becoming an ever-increasing feature of curricula. Technology has created a new type of student whose interest and focus often lie beyond the classroom and engagement in informal learning settings is becoming a feature of education much more.

Perhaps the most challenging dilemma for teachers today is that routine cognitive skills, that are easiest to teach and easiest to test, are also the easiest skills to digitise, automate and outsource, and so are no longer priorities in the world of work. A generation ago, teachers could expect that what they taught would last for the lifetime of their students. Today, where jobs are changing rapidly, education systems need to place much greater emphasis on enabling individuals to become lifelong students, to manage complex ways of thinking and of working that computers cannot take over easily. Students need to be capable not only of constantly adapting but also of constantly learning and growing, of positioning themselves and repositioning themselves in a fast changing world (Schleicher, 2012).

3.2.3 Trends in curriculum developments in revised curricula

It is interesting to note emerging trends in *new curricula* which show a move away from the academic curriculum model to models whose purpose is to improve education and to prepare students for living, learning, and working in the 21st century, as well as developing their discipline knowledge. The new curricula describe what students should be able to do at the end of a course of learning, rather than what should be taught. The development of key competencies, are core to the curricula in which a move towards development of capacities in which active, constructivist pedagogy, puts the student at the centre of learning.

The recent upsurge in curriculum reform globally is partly in response to globalisation, economic competitiveness and citizenship (Yates & Young 2010). Up until recently, the imposition of National Curricula that were defined and controlled by the state was a highly controversial idea in some countries; for example, in the U.S. many educators saw the introduction of the Common Core Standards as undermining their professional judgement, however, over time, most countries have accepted a situation where National control of curricula belongs to governments (Biesta & Priestley 2013), and that classroom control of the contexts in which those curricula are delivered belongs to teachers (Oats, 2011). A dominant influence in curriculum and assessment reform in recent years is international performance testing, whose effect has become known in the literature as the PISA effect (Grek 2009). PISA, and other transnational comparative tests, through its direct impact on national education systems, has become an indirect, but nonetheless influential tool of the new political technology governing education (Grek, 2009) (Breakspear 2012) (Baird et al., 2012). The developments have been strongly influenced by organisations such as the OECD, and the European Union. Such is the publicity and media attention, that the results of these transnational tests may be taken out of the local context, and may have effects on education policy that far outweigh the significance of the results (Dolin & Krogh, 2010).

Across Europe and the English-speaking world, outcomes-based curricula, that are student centred and advocate active pedagogies have been adopted to varying degrees. Newly revised curricula show a number of similar policy trends including: a move from the explicit specification of content towards a more generic, skill-based approach; a greater emphasis on the centrality of the student; and greater autonomy for teachers in developing the curriculum in school (Siennema & Aitken, 2013). Where national curricula are the feature of the education system, there are commonalities both in the goals driving curricula reform and in the emphasis of the policies, as follows:

- To have an influence in improving teacher practice
- To serve equity goals
- To be relevant to 21st century students facing uncertain futures
- To be coherent (Siennema & Aitken, 2013)

Although the precise nature of curriculum developments across the world varies, researchers have identified a number of common features in *new curricula* (Figure 3–3). There is a shift from the prescriptive specification of content to a focus on the centrality of the student and what the student is able to do. This is accompanied by active forms of pedagogy and a view of teachers as facilitators rather than deliverers of learning (Young, 2014) (Siennema & Aitken, 2013) (Yates & Young, 2010). The constructive forms of pedagogy associated with these curricula are said to encourage the development of deep learning (Biesta, 2014)

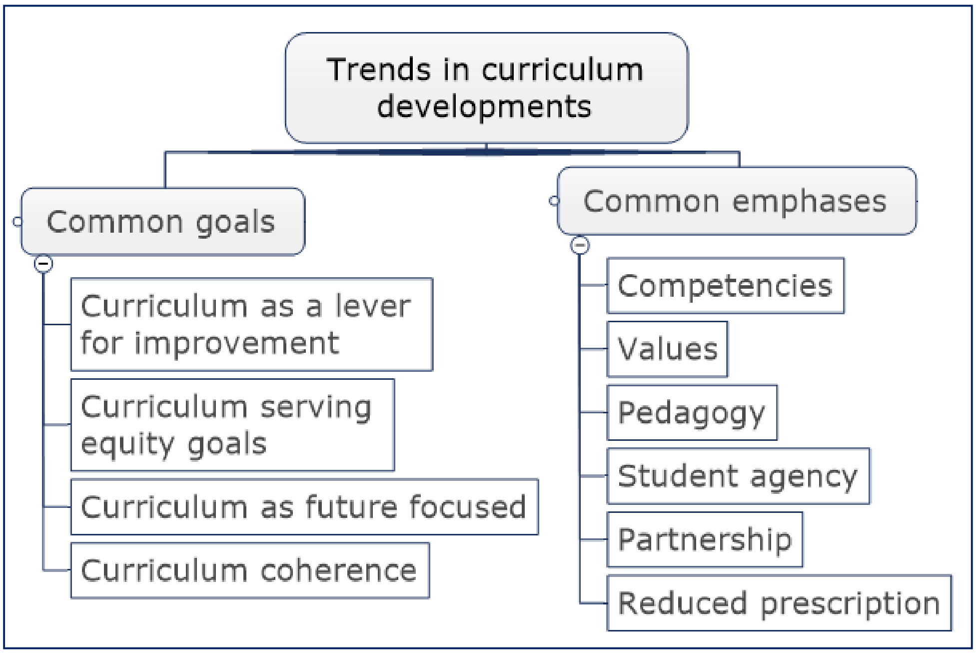

Figure 3-3 Commonalities in national curricula developments (Siennema & Aitken 2013)

Ireland has followed these international trends and the reforms in education currently taking place in Ireland share these comonalities. In their document *Directions for Development* the NCCA set out their goals for curricular reform at senior cycle .

> *……..maintaining and improving the quality of the educational experience for senior cycle students and the quality of the professional experience for those who work with them. They focus on ensuring that the experience provides all students with a foundation for taking advantage of future life chances and work and further education opportunities in a knowledge society. They contribute to an equitable distribution of the benefits of education to all students. They underline the contribution of education to the twin aims of social cohesion and continued economic development (NCCA, 2003d)*

Examples from the core statements on the direction of upper second level education from two countries that consistently perform well on international science and mathematics tests such as PISA and TIMSS are representative of the educational focus for upper second level education internationally- namely Finland and Hong Kong.

Finland

General upper secondary education must provide students with capabilities to meet the challenges presented by society and their environment and the ability to assess matters from different points of view. Students must be guided to act as responsible and dutiful citizens in society and future working life. Upper secondary school instruction must support the development of students' self-knowledge and their positive growth towards adulthood and encourage students towards lifelong learning and continuous self-development. (Finnish National Board of Education, 2004)

Hong Kong

The key challenge for teachers is to put the curriculum aims with regard to content knowledge, generic skills and values into everyday classroom practice to enable students to apply what they have learnt in new and unfamiliar contexts effectively. This implies the development of teachers' professional strengths in the design of learning and teaching strategies and application of a wide range of effective learning experiences, including in particular those that lead to in-depth understanding, enquiry and problem-based learning, and those that engage students in collaborative learning both inside and outside school.(Hong Kong Curriculum Development Council, 2014)

The countries that have made these kinds of education reforms have significantly reduced the amount of curriculum content that students are expected to *cover*, placing greater emphasis on teaching and learning for understanding.

In their paper, *Redesigning Education: Meeting the Challenges of the 21st Century* Microsoft describe a core set of skills that they see as being essential for the 21st century workplace. They argue that whilst the goal of education in the past was standardisation and conformity, today it is about being ingenious, and about personalising educational experiences. The list of skills includes: being knowledgeable about the world, thinking outside the box and being smarter about information, having good people skills, an ability to solve problems, to work as part of a team and ultimately to become a lifelong learner (Butler, Hallissy, Hurley, & Marshall, 2013).

There are many aspects of curriculum reform that are emerging as common to many newly reformed curricula. Siennema and Aitken identify at least four goals underpinning curriculum reform:

- the curriculum as a lever for reform;
- the curriculum serving equity goals;
- the curriculum as future focused; and
- curriculum coherence (Siennema & Aitken, 2013).

The first commonality is national curricula as a lever for reform, implying it as a way of influencing teachers practice. The direct relationship between teaching and student achievement is widely recognised. By influencing different methods of teaching and assessment, policy makers are increasingly focusing on the curriculum to influence the way teacher teach, and in doing so, influence educational improvement. The second commonality, to serve equity goals, recognises the increased participation of a diverse range of learners; inclusion is a desired educational outcome as well as a curricular goal. Thirdly, 21st curricula need to be future focussed, i.e. to serve students whose futures are uncertain. The future jobs and lives of students are not as well defined as in previous decades and pre-determined career paths are less easy to map. Curricula must equip students with adaptive knowledge, understanding and skills to prepare them for this uncertain future. Finally, a curriculum that is coherent is seen as essential to achieving all of the other goals. Coherence at curriculum level is achieved by de-cluttering unwieldy, disconnected content. Curriculum coherence is also sought at a system level in countries that previously have not had national curricula.

The emphases that are described are evident in recently revised curricula to varying degrees; the first is an emphasis on the skills that learners will need to live in the 21st century. The emphasis on competencies is to move beyond content knowledge towards student's competencies for life-long learning. Values in teaching and learning, are seen as increasingly important not as a peripheral consideration, but as a vital element of curriculum design. Curriculum policies increasingly outline teaching approaches as well as learning outcomes, which although generally non-prescriptive, teaching approaches are, in some cases, explicitly linked with learning outcomes. Finally, students are recognised as having the capability and the right to be deeply involved in their own learning, and able to make decisions relating to their education.

Many of these common goals and emphases are expressed in the aim and objectives of curricula, and in many cases show a significant departure from what went before them. In the next section, the curricula of four countries are compared in terms of the aims and objectives set out in them.

3.2.4 Examples of common trends in recently revised curricula

3.2.4.1 Singapore:

The Singapore education system has been known for its academic rigour, down-to-earth direct teaching by the teachers and repeated practice by the students (Lee, 2008). The education system has acknowledged that while the system has achieved *quantity*, the students may not be adequately engaged in the learning process. They become passive learners, driven externally to perform but not necessarily inspired. The catch phrase *teach less, learn more (TLLM)* was coined by the 2004 Minister of Education, Mr Tharman

Shanmugaratnam. TLLM is the way that education in Singapore has moved forward, transforming learning from quantity to quality (Ng Tee, 2008). Figure 3−4 shows the competencies as set out in the Singapore education system.

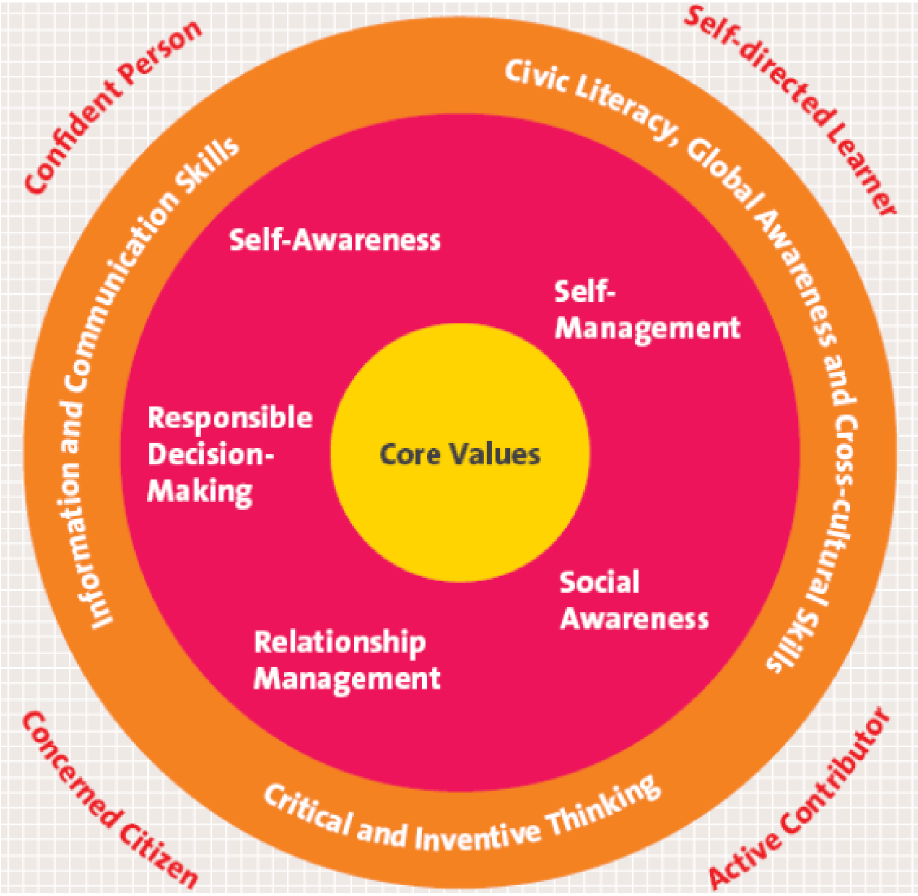

Figure 3-4 Singapore 21st Century competencies

Singapore lists the 21st Century competencies that students will develop:

Knowledge and skills must be underpinned by values. Values define a person's character. They shape the beliefs, attitudes and actions of a person, and therefore form the core of the framework of 21st Century Competencies.

The middle ring signifies the Social and Emotional Competencies – skills necessary for children to recognise and manage their emotions, develop care and concern for others, make responsible decisions, establish positive relationships, as well as handle challenging situations effectively.

The outer ring of the framework represents the emerging 21st Century Competencies necessary for the globalised world we live in. These are:

Civic Literacy, Global Awareness and Cross-Cultural Skills; Critical and Inventive Thinking; Communication, Collaboration and Information Skills

Together, these competencies will enable our young to capitalise on the rich opportunities of the new digital age, while keeping a strong Singapore heartbeat

3.2.4.2 Australia

The new Australian national curriculum, embeds *general capabilities* in the content of the learning areas. The Melbourne Declaration on Educational Goals for Young Australians (MCEETYA, 2008) set out the goal that all young people in Australia should be supported to become successful learners, confident and creative individuals, and active and informed citizens.

The general capabilities encompass the knowledge, skills, behaviours and dispositions that, together with curriculum content in each learning area and the cross-curriculum priorities, will assist students to live and work successfully in the twenty-first century. They complement the key learning outcomes of the Early Years Learning Framework (Coag, 2009) – that children have a strong sense of identity and wellbeing, are connected with and contribute to their world, are confident and involved learners and effective communicators (ACARA 2014)

The Australian Curriculum includes seven general capabilities (Figure 3−5): Literacy; Numeracy; Information and communication technology (ICT) capability; Critical and creative thinking; Personal and social capability; Ethical understanding; Intercultural understanding.

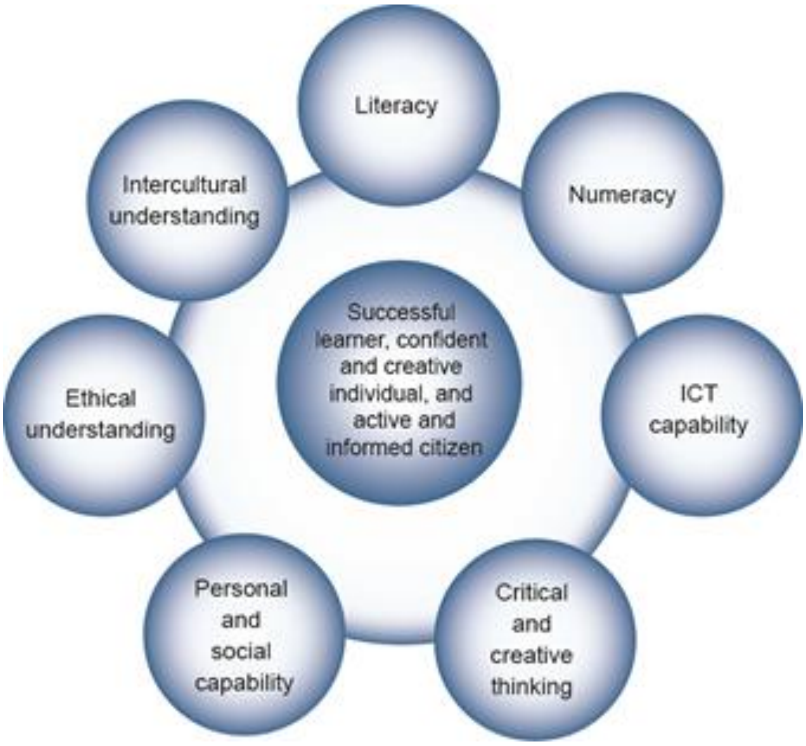

Figure 3-5 General Capabilities as set out in Australian curriculum

The senior second level Australian Curriculum for each subject specifies learning targets and achievement standards. The learning targets describe the knowledge, understanding and skills (Figure 3−6). The achievement standards describe the quality of learning expected of students (Figure 3−8) Teachers use assessment data that they have collected over the period of the learning on which to base these standards. The state and territory authorities determine assessment and certification specifications. The learning outcomes are articulated in the context of disciplinary knowledge. There are overarching outcomes associated with science inquiry and science as a human endeavour, followed by a section entitled *scientific understanding* (Figure 3−7). This provides examples in context.

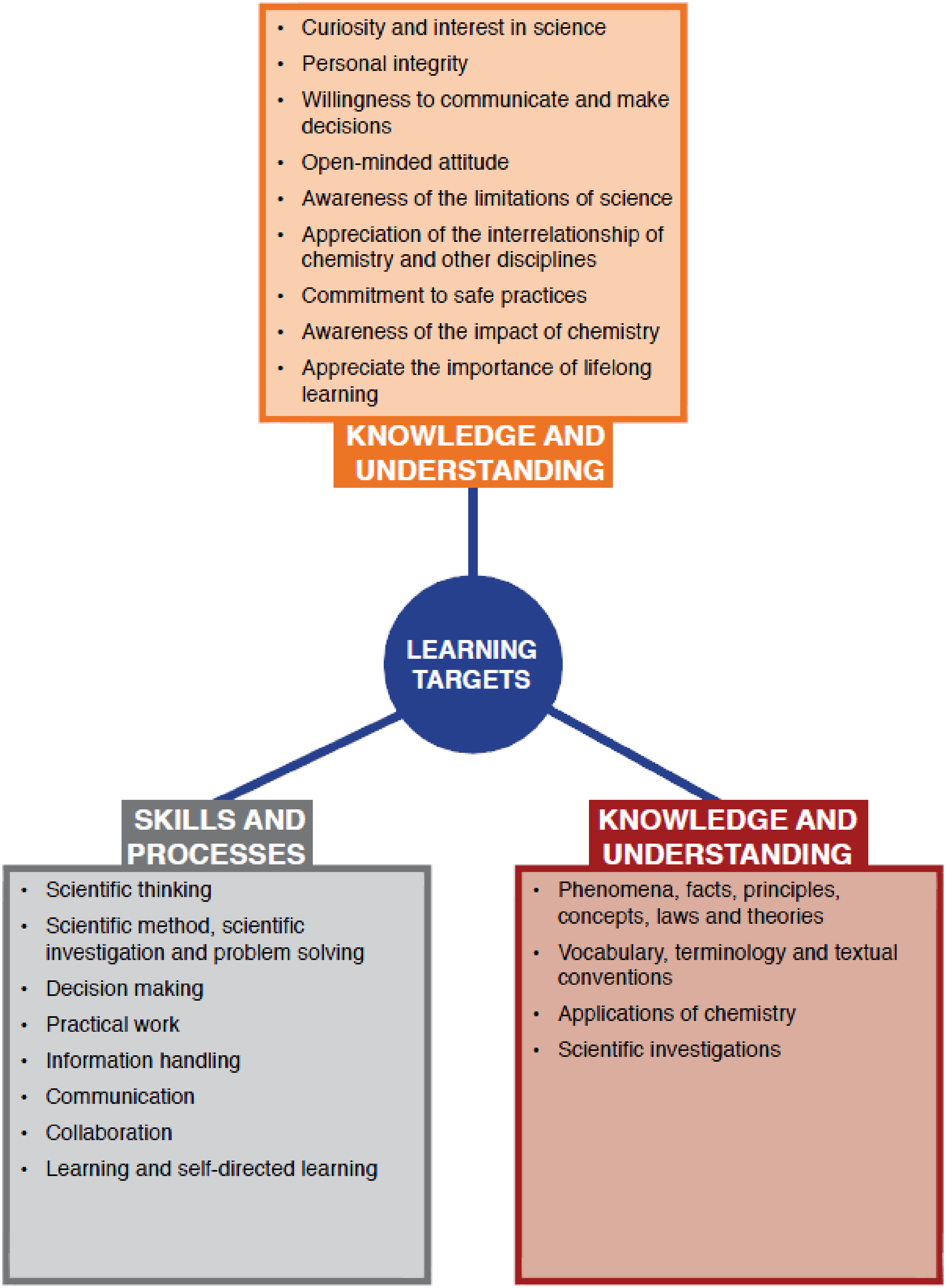

Figure 3-6 Learning targets for chemistry. (Australian National Curriculum)

Science Inquiry Skills

- Identify, research and refine questions for investigation; propose hypotheses; and predict possible outcomes
- Design investigations, including the procedure/s to be followed, the materials required, and the type and amount of primary and/or secondary data to be collected; conduct risk assessments; and consider research ethics
- Conduct investigations, including the use of devices to accurately measure temperature change and mass, safely, competently and methodically for the collection of valid and reliable data

Science as a Human Endeavour

- Science is a global enterprise that relies on clear communication, international conventions, peer review and reproducibility
- Development of complex models and/or theories often requires a wide range of evidence from multiple individuals and across disciplines
- Advances in science understanding in one field can influence other areas of science, technology and engineering
- The use of scientific knowledge is influenced by social, economic, cultural and ethical considerations
- The use of scientific knowledge may have beneficial and/or harmful and/or unintended consequences
- Scientific knowledge can enable scientists to offer valid explanations and make reliable predictions

Science Understanding

Properties and structure of atoms- Examples in Context

- Trends in the observable properties of elements are evident in periods and groups in the periodic table
- The structure of the periodic table is based on the electron configuration of atoms, and shows trends, including in atomic radii and valencies
- Atoms can be modelled as a nucleus surrounded by electrons in distinct energy levels, held together by electrostatic forces of attraction between the nucleus and electrons; atoms can be represented using electron shell diagrams (all electron shells or valence shell only) or electron charge clouds
- Flame tests and atomic absorption spectroscopy are analytical techniques that can be used to identify elements; these methods rely on electron transfer between atomic energy levels
- The properties of atoms, including their ability to form chemical bonds, are explained by the arrangement of electrons in the atom and in particular by the stability of the valence electron shell
- Isotopes are atoms of an element with the same number of protons but different numbers of neutrons; different isotopes of elements are represented using atomic symbols.

Figure 3-7 Outcomes associated with science inquiry and science as a human endeavour (Australian National Curriculum)

Achievement standards	
Chemistry concepts, models and applications	**Chemistry inquiry skills**
For the chemical systems studied the student:	**For the chemical science contexts studied the student**:
analyses how structure, bond strength and energy transfers and transformations are interrelated in chemical systems	designs, conducts and improves safe, ethical investigations that efficiently collect valid, reliable data in response to a complex question or problem
analyses how a range of factors affect atomic or molecular interactions and change the structure and properties of systems	analyses data sets to explain causal and correlational relationships, the reliability of the data, and sources of error
explains the theories and model/s used to explain the system and the aspects of the system they include	justifies their selection of data as evidence, analyses evidence with reference to models and/or theories, and develops evidence-based conclusions that identify limitations
applies theories and models of systems and processes to explain phenomena, interpret complex problems, and make reasoned, plausible predictions in unfamiliar contexts	evaluates processes and claims, and provides an evidence-based critique and discussion of improvements or alternatives
For the chemical science contexts studied, the student:	selects, constructs and uses appropriate representations to describe complex relationships and solve complex and unfamiliar problems
analyses the roles of collaboration, debate and review, and technologies, in the development of chemical science theories and models	communicates effectively and accurately in a range of modes, styles and genres for specific audiences and purposes
evaluates how chemical science has been used in concert with other sciences to meet diverse needs and inform decision making, and how these applications are influenced by interacting social, economic and ethical factors	

Figure 3-8 Extract of achievement standards chemistry in Australian national curriculum

3.2.4.3 Hong Kong[16]

The senior second level education system in Hong Kong was restructured in 2009. The curriculum was overhauled substantially by the conversion of the two-year Certificate Level and the two-year Advanced Level to a new three-year senior second level (Hong Kong Curriculum Development Council, 2014).

The curriculum is set out as a curriculum guide. It sets out what is expected, but acknowledges that the expectations may not be appropriate for all students. Teachers are asked to exercise their professional judgement in the planning and delivery of a broad and balanced curriculum suitable for all students and to organise the curriculum in different ways to ensure fitness for purpose.

For each subject, the learning targets are outlined under values and attitudes, skills and processes and knowledge and understanding (Figure 3−9). The curriculum guide outlines major concepts and important principles to be acquired; it lists learning objectives, and learning outcomes to be achieved by students in the curriculum. It provides a broad framework upon which learning and teaching activities can be developed. Teachers are provided with suggested teaching and learning activities that may enable students to acquire some of the skills associated with the topic. The list includes a wide range of activities, such as discussion, debate, practical work, investigations and information searching. Teachers use their professional judgement to arrange learning activities that will develop the knowledge and skills listed in the learning objectives and learning outcomes.

[16] http://334.edb.hkedcity.net/doc/eng/curriculum/Chem%20C&A%20Guide_updated_e.pdf

Values and Attitudes

Students are expected to develop, in particular, the following values and attitudes:

- to appreciate that scientific evidence is the foundation for generalisations and explanations about matter
- to appreciate the usefulness of models and theories in helping to explain the structures and behaviours of matter
- to appreciate the perseverance of scientists in developing the Periodic Table and hence to envisage that scientific knowledge changes and accumulates over time
- to appreciate the restrictive nature of evidence when interpreting observed phenomena
- to appreciate the usefulness of the concepts of bonding and structures in understanding phenomena in the macroscopic world, such as the physical properties of substances

Figure 3-9 Values and attitudes as stated in the Hong Kong National Curriculum

For each stage, some desirable values and attitudes that can be related to particular topics are highlighted. Through discussion and debate, students are encouraged to develop value judgements and good habits for the benefit of themselves and society. Teachers are encouraged to use a variety of teaching and learning activities, and some examples are provided (3−10).

Suggested teaching activities and interconnections between science, technology, society and the environment are also suggested for each topic Figures 3−10, and 3−11.

Suggested Learning and Teaching Activities

Students are expected to develop the learning outcomes using a variety of learning experiences. Some related examples are:

- searching for and presenting information on the discoveries related to the structure of an atom
- searching for and presenting information on elements and the development of the Periodic Table
- performing calculations related to relative atomic masses, formula masses and relative molecular masses
- drawing electron diagrams to represent atoms, ions and molecules

Figure 3-10 Suggested learning and teaching activities in Hong Kong National Curriculum

STS Connections

Students are encouraged to appreciate and comprehend issues which reflect the interconnections of science technology and society and the environment. Related examples are:

- Using the universal conventions of chemical symbols and formulae facilitates communication among people in different parts of the world.
- Common names of substances can be related to their systemic names (e.g. table salt and sodium chloride, baking soda and sodium hydrogen carbonate.
- Some specialised new materials have been created on the basis of findings of research on the structure, chemical bonding and other properties of the matter (e.g. bullet–proof fabric, superglue)

Figure 3-11 Suggested STS connections in Hong Kong National Curriculum

3.2.4.4 United States[17]

The NGSS are built around a three dimensional model, where the disciplinary core ideas are framed in science and engineering practices, and cross cutting concepts (Figure 3−12).

Scientific practices	Cross cutting concepts
• Asking questions (for science) and defining problems (for engineering) • Developing and using models • Planning and carrying out investigations • Analysing and interpreting data • Using mathematics and computational thinking • Constructing explanations (for science) and designing solutions (for engineering) • Engaging in argument from evidence • Obtaining, evaluating, and communicating information	• Patterns • Cause and effect • Scale proportion and quantity • Systems and system models • Energy and matter: Flows, cycles, and conservation. • Structure and function • Stability and change

Figure 3-12 Next Generation Science Standards Scientific practices and cross cutting concepts

The learning outcomes in the NGSS are articulated, along with specific expectations in each of the dimensions. For each learning outcome there are clarification statements and assessment boundaries. The NGSS provide a lot of detail to support planning for teaching; however, teachers are not told how to teach or what to teach. For each of the disciplinary learning outcomes, examples of how the application of the practices and the cross cutting concepts could be used in the teaching of the core ideas are described. This provides a coherent structure on which teachers can plan their teaching.

[17] http://www.nextgenscience.org/next-generation-science-standards

3.3 Ways in which the big ideas in the curricula are communicated

How teachers interpret curricula is critical to their successful implementation. The intended curriculum will only become the implemented one if there is a shared understanding between policy makers and practitioners. A view of how different national curricula from around the world are communicated to teachers provides an interesting perspective on the discussion about national curricula, and interpretation of intended learning outcomes, and there are lessons to be learned from how other countries do things. However, no education system or its assessment can be viewed in isolation. An education system evolves from a culture, and is part of that culture. A recent report from OFQUAL comparing assessment at upper second level internationally put it well when it states

> *...any comparability study which takes one dimension of education in isolation, removing it from its context, is flawed. It is crucial that any variable should not be judged in isolation, and that we acknowledge that assessments are a product of the society, culture, political and educational systems within which they sit (OFQUAL, 2008)*

The upper second level curricula of Ontario, Scotland, New South Wales and the International Baccalaureate will be used to illustrate how broad learning outcomes are communicated, and how skills development and application of knowledge and understanding to real-life contexts is communicated through the curriculum documents. These curricula were chosen as they represent a wide spread across three continents, Australia, North America, and Europe, and an international curriculum offered in 146 countries across the world. Each is centrally developed and, with the exception of Ontario, each has an externally assessed written examination at the end of a two-year course, and a second, practically based component of assessment. Each curriculum has recently been reviewed, is written in English, and is accompanied by curriculum, assessment and teacher support material that is readily accessible. They each emphasise skills development through science learning, with a strong emphasis on practical engagement throughout the course.

3.3.1 Ontario

The Ontario upper second level curriculum sets out the course in terms of the overall expectations and the specific expectations that outline the knowledge and skills that students are expected to develop and demonstrate.

The curriculum combines the three disciplines of biology, chemistry and physics in one science curriculum. There is a common preamble describing the programme for science, and the assessment and planning for teaching and learning. The learning expectations for physics, biology, and chemistry are each organised into six distinct but related strands. The first strand (strand A) focuses on scientific investigation skills, and is the same for each subject. The scientific investigation skills are organised under sub-headings related to the four broad areas of investigation – initiating and planning; performing and recording; analysing and interpreting; and communicating (Figure 3−13).

The remaining five strands (strands B to F) in each subject represent the major content areas for each subject and are expressed as learning outcomes. These learning outcomes are quite broad and rich and relate extremely well to learners' everyday lives. They are grouped under three headings: relating science to technology, society and the environment, developing skills of investigation, and understanding basic concepts.

The strands also contain some examples of relevant topics or open-ended issues or problems. Learners can explore and debate the examples given, or choose their own issues to debate, forming and justifying their own conclusions. They can also provide students with a focus for inquiry and/or research. The examples from Ontario demonstrate very effectively how to pose questions that open students to the kind of inquiry where they find answers for themselves.

In summary, the Ontario curriculum presents a common overarching unit on skills associated with scientific practices for each of the science subjects. Also, the examples of the types of issues and questions that learners should be able to discuss and investigate provide a very good illustration of how learning outcomes in the affective domain can be included, see Figure 3−14. These learning outcomes encourage learners to explore and debate scientific concepts.

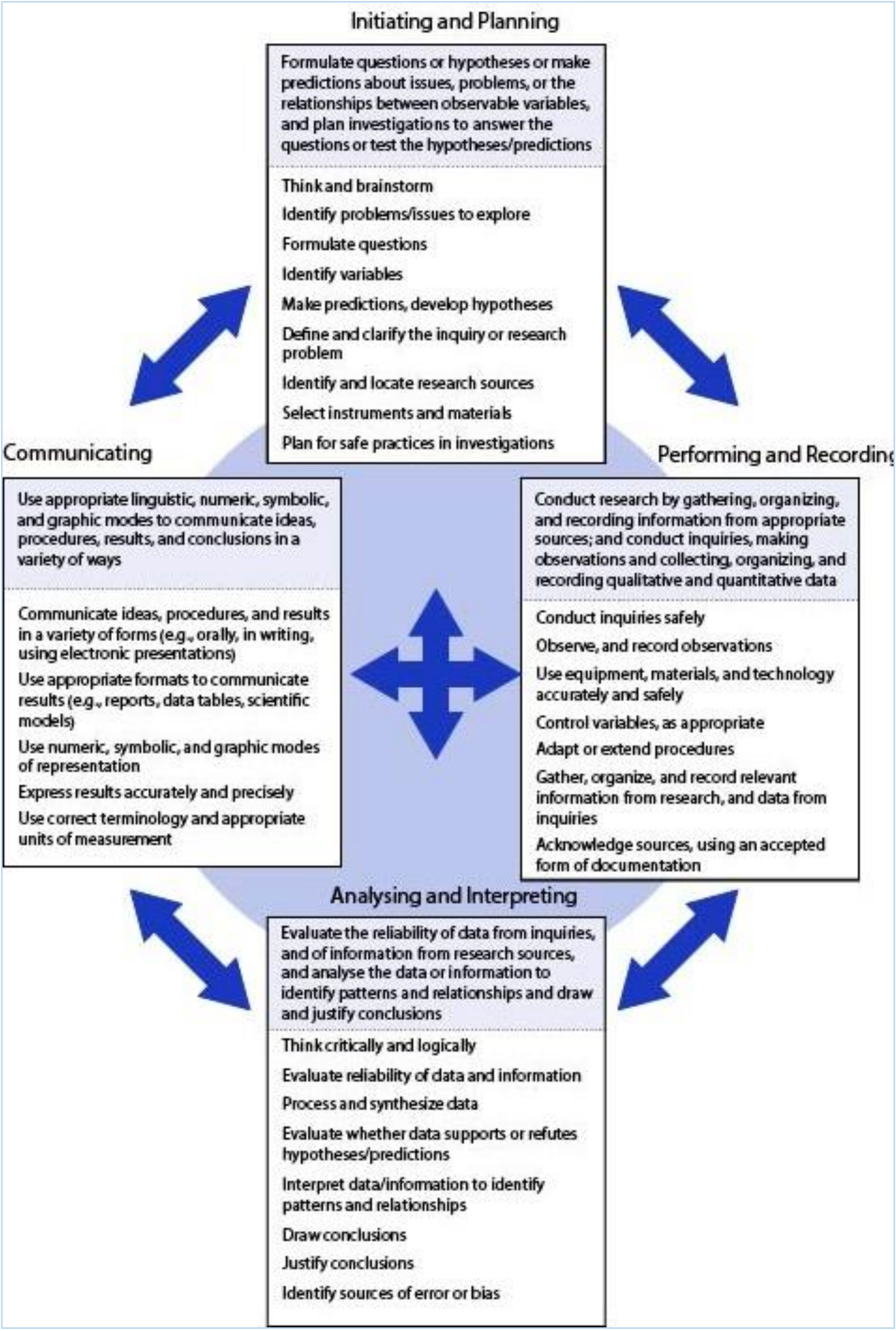

Figure 3-13 Scientific investigation skills Ontario Curriculum

Relating science to Technology, Society and the Environment	
By the end of this course students will: Present informed opinions on the validity of the use of the terms organic, natural and chemical in the promotion of consumer goods Describe the variety and importance of organic compounds in our lives (e.g. plastics, synthetic fibres, pharmaceutical products)	– Analyse the risks and benefits of the development and application of synthetic products (e.g., polystyrene, aspartame pesticides, solvents) – Provide examples of the use of organic chemistry to improve technical solutions to existing or newly identified health, safety and environmental problems (e.g. leaded versus unleaded gasoline, hydrocarbon propellants, versus chlorofluorohydrocarbons).

Figure 3-14 Learning outcomes relating to science technology society and the environment. Ontario Curriculum

3.3.2 Scotland

Scotland has recently revised the Scottish Highers, which had been in place since 1999. Although uptake of the sciences was strong before the revision, there was a call for more modern and engaging science courses, which would contribute to the development of greater scientific knowledge and skills, and that would be in line with Curriculum for Excellence[18]. As part of the revision, the Higher science subject courses[19] were revised. Content was reduced and greater focus was placed on application and process, with a greater emphasis on skills in the assessment.

In the revision, many of the fundamental science concepts and theories from the previous courses were retained, but in the revised courses the focus is on engagement with these through problem solving. This problem solving approach is supported in assessment by a range of question types, which rely on application of knowledge and understanding and an ability to think critically. One example is the open-ended question for which there is no correct answer. Students use their deep understanding of science principles and concepts

[18] SQA website http://www.sqa.org.uk/sqa/48220.html

[19] http://www.sqa.org.uk/sqa/58085.3588.html

to comment on an everyday context, for example the physics of snowboarding, or the chemistry of an ice pack.

> *Open-ended questions are designed to encourage a full and meaningful answer using the student's knowledge of physics. Such a question therefore allows a student the opportunity to demonstrate a deeper understanding of physics principles than can be demonstrated by familiar quantitative-type problems (SQA 2010, Open-ended Questions, support materials)*

The Scottish Higher course specification is a short, 10-page document (extract shown in Figure 3−15) that lists the mandatory course key areas. It also describes the skills that students should develop. Each course is divided into units containing statements of standards for assessment.

Another short document (Unit Outline) provides information on assessment standards and evidence of requirements for each unit.[20]

As well as the course specification and unit outline, and in order to help teachers plan for teaching and learning, the Scottish Qualifications Authority (SQA) has produced support notes that provide examples of teaching and learning strategies and exemplification of key areas (Figure 3−16). The support material is not presented as a *how to* resource; rather, it is presented as educative curriculum material that offers teachers the freedom to use contexts or teaching and learning methods that they feel are appropriate, while at the same time providing guidance through examples linked to specific areas of content.

[20] http://www.sqa.org.uk/files_ccc/CfE_Unit_H_Chemistry_ChemicalChangesandStructure.pdf

Outline of Chemical Structure
Chemical Changes and Structure (Higher) This Unit covers the knowledge and understanding of controlling reaction rates and periodic trends, and strengthens the learner's ability to make reasoned evaluations by recognising underlying patterns and principles. Learners will investigate collision theory and the use of catalysts in reactions. Learners will explore the concept of electronegativity and intra-molecular forces. The connection between bonding and ma material's physical properties is investigated.
Outline of Unit assessment for Chemical Changes and Structure
Unit assessment All Units are internally assessed against the requirements shown in the Unit Specification. They can be assessed on a Unit-by-Unit basis or by combined assessment. They will be assessed on a pass/fail basis within centres. SQA will provide rigorous external quality assurance, including external verification, to ensure assessment judgements are consistent and meet national standards. The assessment of the Units in this Course will be as follows. Chemical Changes and Structure (Higher) Learners who complete the Unit will also be able to: • apply skills of scientific inquiry and draw on knowledge and understanding of the key areas of this Unit to carry out an experiment • draw on knowledge and understanding of the key areas of this Unit and apply scientific skills

Figure 3-15 Extract from the new Scottish Higher Chemistry Course Specification

The Mandatory Course key areas are from the Course Assessment Specification. Activities in the Suggested learning activities are not mandatory. This offers examples of suggested activities, from which you could select a range of suitable activities. It is not expected that all will be covered. Centres may also devise their own learning activities. Exemplification of key areas is not mandatory. It provides an outline of the level of demand and detail of the key areas. Risk assessment should always be carried out by teachers/lecturers prior to doing any of the experiments and demonstrations listed in the table.		
Chemical Changes and Structure		
Mandatory Course key areas	**Suggested learning activities**	**Exemplification of key areas**
Controlling the rate of Collision theory explaining rates of reaction and activation energy. Relative rate of reaction	Several experiments and animations can be used to demonstrate the factors that affect reaction rates. Learners can investigate the effect of concentration on reaction rate by dropping a strip of magnesium into various concentrations of hydrochloric acid and recording the time taken for the effervescence to stop. An unusual experiment demonstrating the effect of concentration on reaction rate is provided in the decolourisation of permanganate using rhubarb as described in the Practical Chemistry website from the Royal Society of Chemistry and the Nuffield Foundation.	Reaction rates can be controlled by chemists. If they are too low a manufacturing process will not be economically viable, too high and there is a risk of thermal explosion. Collision theory can be used to explain the effects of concentration, pressure, surface area (particle size), and temperature and collision geometry on reaction rates.

Figure 3-16 Extract from Higher Chemistry Support Notes. Scottish Qualifications Association

The revision of the Highers in science subjects also introduced a change to the way that practical science is carried out. There has been a move from a list of highly prescriptive mandatory experiments to a situation where the learners or their teacher choose what experiments to do and how they do them. Separate extensive support material for students, to help them to research, carry out and communicate investigations, is also provided on the Education Scotland website[21]. As part of their course, students are expected to produce a single scientific communication, which is a report of an investigative activity and its findings. Depending on the activity, the collection of information may involve group work. The scientific communication can take any of the following forms: poster, PowerPoint presentation, video presentation and web page. There is no specified content for the communication, or the topic chosen.

In summary, the developments in Scotland provided a good illustration of the international move towards presenting learning outcomes about fundamental science concepts that have a greater focus on problem solving and inquiry. The assessment of the learning outcomes is through application of knowledge and understanding. The extended investigation is a good example of independent research in both experimental investigations and investigations of scientific issues.

3.3.3 International Baccalaureate

The International Baccalaureate (IB) is assessed by a written end-of-course examination, and a practical examination. The written paper (74%) is set and marked externally. The practical examination (26%) is internally assessed. The syllabus is organised by topics; Standard Level (SL) students study eight topics and Higher level (HL) students study a further six. In addition, both SL and HL students study two out of a choice of seven (at SL) or six (at HL) optional topics[22].

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[21] http://www.educationscotland.gov.uk/supportinglearners/

[22] https://store.ibo.org/

The IB documentation refers to the strong impact of high-stakes assessment on teaching and learning. It highlights how assessment, including summative end-of-course assessment, is used to direct teaching and learning through well-designed assessment instruments that encourage good pedagogy and constructive student involvement in their own learning.

> *If the aim of the DP[23] is to achieve the development of students who are inquiring, knowledgeable and caring and who become active, compassionate and lifelong learners (IB mission statement), then these characteristics should be reflected in the assessment system. It is an inevitable fact that what is not assessed is not so highly valued and may even be overlooked altogether. The aspirations expressed in the mission statement must be supported by the assessment system (IBO, 2013)*

The current (2007) IB Diploma Program Subject Guide lists statements of what learners should be able to do. The domination of the high stakes end of course assessment is a feature of the IB that resonates with assessment in Ireland. To assist the clarification of learning outcomes, and to help learners and teachers understand what is required, broad assessment statements are accompanied by teacher's notes (Figure 3−17). The teacher's notes support teachers to guide learners towards learning outcomes; they do not specify the precise content or method. The documentation also includes a list of assessment command terms. The command terms indicate precisely what the learner is expected to do with the subject content. Placing emphasis on the meaning of the command term focuses attention on process rather than product.

The 2007 syllabus has since been revised and will be examined for the first time in 2016. The revised syllabus is presented in Diploma Program Subject Guides, organised into topics and sub-topics Figure 3−18. The assessment statements are replaced by essential ideas. Each essential idea has a description on alignment of learning with the nature of science. The learning is categorised as: *Understandings*, which are the main ideas to be

[23] Diploma Program

learned; *Applications and skills*, which are the specific applications and skills to be developed from the understandings; *Theory of knowledge and Utilisation*.

	Assessment statement	Obj	Teacher's notes
5.21	Calculate the heat energy change when the temperature of a pure substance is changed	2	Students should be able to calculate the heat energy changes for a substance given the mass, specific heat capacity and temperature change using $q = mc\theta$
5.22	Design suitable experimental procedures for measuring the heat energy changes of a reaction	3	Students should consider reactions in aqueous solutions and combustion reactions. Use of the calorimeter and bomb calorimeter will not be assessed Aim 7: Dataloggers and databases can be used here
5.23	Calculate the enthalpy change for a reaction using experimental data on temperature changes, quantities of reactants and mass of water	2	
5.24	Evaluate the results of experiments to determine enthalpy change	3	Students should be aware of the assumptions made and the errors due to heat loss TOK: What criteria do we use in judging whether discrepancies between experimental and theoretical values are due to experimental limitations or theoretical assumptions?

Figure 3-17 IB Diploma Program Subject Guide (2007)

<table>
<tr><td colspan="2">2.5 Enzymes</td></tr>
<tr><td colspan="2">Nature of science:
Experimental design – accurate, quantitative measurements in enzyme experiments require replicates to ensure reliability</td></tr>
<tr><td>Understandings:
• Enzymes have an active site to which specific substances bind
• Enzyme catalysis involves molecular motion and the collision of substrates with the active site
• Temperature, substrate concentration and Ph affect the rate of activity of enzymes
• Enzymes can be denatured
• Immobilized enzymes are used widely in industry
Application and skills:
• Application: Methods of production of lactose free milk and its advantages
• Skill: Design of experiments to test the effect of temperature, Ph, and substrate concentration on the activity of enzymes
• Skill: Experimental investigation of a factor affecting enzyme activity
Guidance:
• Lactase can be immobilised in alginate beads and experiments can then be carried out in which the lactose in milk is hydrolysed
• Students should be able to sketch graphs to show the expected effects of temperature, Ph and substrate concentration on the activity of enzymes. They should be able to explain the patterns or trends in these graphs</td>
<td>Theory of knowledge:
• Development of some techniques benefits particular human populations more than others. For example, the benefit of lactose free milk available in Europe and North America would have greater benefit in Africa/Asia where lactose intolerance is more prevalent. The development of techniques requires financial investment. Should knowledge be shared when techniques developed in one part of the world are more applicable that others?
Utilisation
• Enzymes are extensively used in industry for the production of items from fruit juice to washing powder
Syllabus and cross curricular links:
Biology
Topic 8AHL Metabolism, cell respiration and photosynthesis</td></tr>
</table>

Figure 3-18 Extract from revised IB Diploma Program Subject Guide (2016)

3.3.4 New South Wales

The exit examination in New South Wales (NSW) is the Higher School Certificate (HSC). There are two years of study leading to the HSC examination, comprising a preliminary course and a Higher School Certificate.

Science at this stage of education in NSW is seen as providing a context within which to develop general competencies considered essential for the acquisition of effective, higher-order thinking skills necessary for further education, work and everyday life. Key competencies are embedded in the specification to enhance student learning and are explicit in the objectives and outcomes set out. The NSW specification provides a useful illustration of key skills embedded in learning outcomes.

In each of the biology, chemistry and physics specifications, there is an identical overarching unit that describes learning outcomes in relation to planning and conducting investigations, communicating information and understanding, scientific thinking and problem solving, and working individually as well as in teams. The specification sets out broad learning outcomes but does not provide details of how learners reach them. The content is listed in a column and a second column outlines suggested activities (Figure 3−19).

HSC Course Outcomes	Content
A student: justifies the appropriateness of a particular investigation plan	**Students: identify data sources to:** analyse complex problems to determine appropriate ways in which each aspect may be researched determine the type of data which needs to be collected and explain the qualitative or quantitative analysis that will be required for this data to be useful identify the orders of magnitude that will be appropriate and the uncertainty that may be present in the measurement of data identify and use correct units for data that will be collected recommend the use of an appropriate technology or strategy for data collection or gathering information that will assist efficient future analysis
	plan first-hand investigations to: demonstrate the use of the terms 'dependent' and 'independent' to describe variables involved in the investigation identify variables that need to be kept constant, develop strategies to ensure that these variables are kept constant, and demonstrate the use of a control design investigations that allow valid and reliable data and information to be collected design and trial procedures to undertake investigations and explain why a procedure, a sequence of procedures or repetition of procedures is appropriate predict possible issues that may arise during the course of an investigation and identify strategies to address these issues if necessary
	11.3 choose equipment or resources by: identifying and/or setting up the most appropriate equipment or combination of equipment needed to undertake the investigation carrying out a risk assessment of intended experimental procedures and identifying and addressing potential hazards identifying technology that could be used during investigations and determining its suitability and effectiveness for its potential role in the procedure or investigations recognising the difference between destructive and non-destructive testing of material and analysing potentially different results of these two procedures

Figure 3-19 Overarching unit on chemistry skills New South Wales curriculum

The NSW specification is a good example of the alignment of practical activities with theoretical learning outcomes. Specifying the types of activity ensures that a range of skills is developed and that theory is constantly underpinned by practice.

3.4 International comparison of assessment of practical work

Despite the challenges and complexities associated with the assessment of practical science, it is included in high stakes examinations internationally because it measures what cannot be measured in a written examination, such as the collection and recording of primary data, and manipulative skills. A lot of the discussion around the assessment of practical work centres on the difficulty in assessing process (direct assessment of practical skills, DAPS) rather than product (indirect assessment of practical skills, IAPS). A recent report commissioned by the Gatsby foundation, *Improving the assessment of practical work in school science* (Reiss et al., 2012) provides a very useful summary of the essential elements of both types of assessment, and the types of practical assessment in which they are used (Tables 3−4 and 3−5).

Types of practical assessment	**DAPS or IAPS**
Report on an investigation – students write their report on an investigation using their own data but their practical skills are not observed or assessed directly	IAPS
Report on an investigation – students write their report on an investigation using data with which they have been provided (typically because of a problem that has prevented the student from obtaining any meaningful data)	IAPS
Written examination – students complete a test paper that includes questions about practical work under examination conditions	IAPS
Practical examination report – students conduct a practical and write up their apparatus, methods, results and evaluations	IAPS
Practical examination – teacher (or other examiner) observes students undertaking practical work	DAPS

Table 3-4 Categorisation of practial activities

	DAPS	IAPS
What is the principle of the assessment?	A student's competency at the manipulation of real objects is directly determined as they manifest a particular skill	A student's competency at the manipulation of real objects is inferred from their data and/or reports of the practical work they undertook
How is the assessment undertaken?	Observations of students as they undertake a piece of practical work	Marking of student reports written immediately after they undertook a piece of practical work or marking of a written examination paper subsequently taken by students
Advantages	High validity Encourages teachers to ensure that students gain expertise at the practical skills that will be assessed	More straightforward for those who are undertaking the assessment
Disadvantages	More costly Requires teachers or others to be trained to undertake the assessment Has greater moderation requirements	Lower validity Less likely to raise students' level of practical skills

Table 3-5 Comparison of DAPS, the Direct Assessment of Practical Skills, and IAPS, the Indirect Assessment of Practical Skills(Reiss et al., 2012)

Correlations between learners' performances with real equipment and their responses to equivalent written tests are low (Black, 1990). Indeed, the difficulty in finding an ideal solution to practical assessment explains why this area of assessment is undergoing continuous research and development. Various methods of practical assessment have been tried in different countries (Reiss et al., 2012).

3.4.1 Examples of practical assessment from a selection of countries

Examples of practical assessments are now discussed in relation to the distinction between DAPS and IAPS. The assessment practices of eight different countries are outlined.

3.4.1.1 Singapore

Singapore is an example of a country that uses DAPS in a practical examination. Before 2004, assessment of practical skills was by way of a once off practical examination as part of the Singapore-Cambridge General Certificate Advanced Level[24.] This has now changed to a teacher assessed, classroom based assessment of:

- MMO: Manipulation, Measurement and Observation,
- PDO: Presentation of Data and Observation and
- ACE: Analysis, Conclusions and Evaluation.

Students are directly assessed on the three skill areas as they perform two tasks over 1hour 15 minutes. The tasks are externally set and distributed to schools within a certain period prior to the assessment.

The Assessment is carried out by the teacher during class time.

3.4.1.2 New Zealand

In New Zealand[25,] practical work at upper second level is teacher assessed but externally moderated. Students carry out an open-ended investigation to solve a research problem. Students are posed the research question such as the following in chemistry:

> *This activity requires you to investigate the concentration of sodium hypochlorite in swimming pool water under different conditions (such as UV*

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[24]http://www.seab.gov.sg/aLevel/syllabus/schoolCandidates/2014_GCE_A.html

[25] http://ncea.tki.org.nz/Resources-for-Internally-Assessed-Achievement-Standards/Science/Chemistry/Level-3-Chemistry

exposure, pH, or concentration of chlorine stabilisers). You have approximately two to three weeks of in-class time to complete this task.

The students are marked on their performance, as well as on their report of the investigation. This represents a good example of a country that employs a combination of DAPS and IAPS.

3.4.1.3 Wales[26]

Students select to carry out two practical experiments from three practical areas, for example in chemistry from:

- Energetics and thermochemistry
- Rates of reaction and kinetics
- Volumetric analysis and stoichiometry

Students work independently in an open-book set up. They have access to their notes, textbooks or other resources. Candidates are required to sign a declaration stating that all work is their own. Their teacher countersigns the declaration.

The work is completed on a pro-forma; students are not allowed to take the pro forma out of the laboratory. The pro-forma is marked externally, and assessment is based on IAPS.

3.4.1.4 England

The awarding body for qualifications in England is the Assessment and Qualifications Alliance (AQA). It compiles specifications and holds examinations in various subjects. From 2015 (first examination in 2017) practical assessment will not form part of the overall assessment of science; however, teachers will have to confirm that students have carried out a series of pre-specified practical activities. Teachers award students with a *Pass* or a *Blank*. The current method of practical assessment is outlined below. Until 2017, practical work is worth 15% of the total marks; 20% at AS level and 10% at A2 level. Different

[26] http://www.wjec.co.uk/qualifications/chemistry/chemistry-gce-a-as/#related-documents-section

awarding bodies employ different methods of practical assessment. Students have a choice of routes for Practical Skills Assessment. (Table 3−6).

Available marks for AQA AS and A2 Sciences					
	Route T: Teacher Assessed – percentage of marks			Route X: Externally Marked – percentage of total marks	
		Practical Skills Assessment	Investigative Skills Assessment	Practical Skills Verification	Externally Marked Practical Assignment
Unit 3 – Internal Assessment Investigative and practical skills in AS	Biology	12	88		100
	Chemistry	24	76		100
	Physics	18	82		100
Unit 6 – Internal Assessment Investigative and practical skills in A2	Biology	12	88		
	Chemistry	24	76		100
	Physics	18	82		100

Table 3-6 Practical Assessment AQA England.

The externally marked route X entails an Externally Marked Practical Assignment (EMPA) that carries 50 marks and involves three stages. Stage 1 is where students carry out the practical work following AQA specifications, stage 2 is the processing of the data, where students write up their findings, and stage 3 is the EMPA written test where students answer questions on their own data and questions on additional data related to the topic, analysis and evaluation. Whilst the EMPA is assessed solely using IAPS, there is a requirement for what is termed Practical Skills Verification (PSV), which requires teachers to verify their candidates' ability to demonstrate safe and skilful practical techniques and make valid and reliable observations. Whilst the Practical Skills Verification does not contribute towards the assessment mark the student can only pass the unit if the teacher verifies that the student has completed the practical task – an example of a very basic DAPS.

3.4.1.5 Scotland[27]

There is only one awarding body for standard grade and higher. In the Higher courses, students carry out an open-ended investigation in which the teacher verifies that the report is the individual work of the candidate: The report must include:

- planning the experiment deciding how it is to be managed
- identifying and obtaining the necessary resources, some of which must be unfamiliar
- carrying out the experiment
- evaluating all stages of the experiment, including the initial analysis of the situation
- planning and organising experimental procedures

The assessment is based on IAPS as opposed to DAPS because students are not marked on their direct manipulation of objects.

3.4.1.6 Finland[28]

Practical assessment is carried out by the teacher and includes course tests, monitoring of the degree of active participation, experimental work, work reports, projects, presentations and research papers. It is based on a combination of DAPS and IAPS.

The skills that are assessed are:

- making observations, planning and implementation of measurements and experiments

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[27] http://www.sqa.org.uk/sqa/39857.html

[28] FNBE (2004). National Core Curriculum for Basic Education 2004. Helsinki: National Board of Education.

- safe use of equipment and reagents
- presentation of results both orally and in writing

3.4.1.7 Australia

Examinations are determined at state level; in each of the six states assessment of practical work is different. In Queensland and the Australian Capital Territory, school-based examinations take place but in the other five states and the Northern Territory state-based external examinations are used.

Practical work is assessed for students in Year 12 throughout Australian schools and is usually worth from 10% to 30% of the total marks. One example which is aimed at high attaining students is The International Competitions and Assessments for Schools [29] (ICAS) Science which assesses skills in the following scientific areas:

- interpreting data, including observing, measuring and interpreting diagrams, tables and graphs
- applying data, including inferring, predicting and concluding
- higher order skills, including investigating, reasoning and problem solving

ICAS is a multiple choice test and does not directly assess practical skills in science. Whilst the test does include items about interpreting data and understanding experimental design, the competency of the students' skills are only inferred (IAPS).

3.4.1.8 France[30]

The assessment of practical work involves two parts, a written test for 16 marks and a practical test for 4 marks, making a total of 20 marks. The practical test lasts for an hour. Whilst the students are carrying out the practical work, two teachers assess four students at a time (DAPS); however, the teachers do not examine their own students but those of their colleagues. The practical work that is assessed annually is randomly selected from a

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[29] https://www.eaa.unsw.edu.au/icas/subjects/science

[30] http://www.education.gouv.fr/bo/2004/9/MENE0400274N.htm

prepared list of possible activities that the students have been prepared for during the course. Teachers use an observation grid that looks at four specific areas:

- understand how and why to manipulate
- use of techniques
- use of methods to represent the experimental data
- apply an explanatory approach

After this, students go onto the written part, the IAPS component.

The first area, understand how and why to manipulate, assesses students' justification for their choice of equipment or method that is linked to their hypothesis. The second area, use of techniques, assesses students' abilities at using the equipment correctly, as well as the use of simulation software. The third area, use of methods to represent the experimental data, assesses students at their ability to select and use the information to record using, for example, drawings and tables in a suitable way. The fourth area, apply an explanatory approach, assesses students' ability in argumentation and understanding of the experiment, understanding the problems in the experiment, commenting on results and evaluating them.

3.5 Curriculum coherence

The inclusion of rich, open learning outcomes allows for flexibility and for teachers to use their expertise and professional judgement in planning for teaching, learning, and assessment. This requires a careful consideration of how to ensure that there is curriculum coherence. The National Curriculum – indeed any centralised statement of core standards – is only one part of the totality of the curriculum. It is impossible to list the skills, attitudes, values and knowledge that a learner should develop in each of the learning outcomes, and to do so would undermine the whole process. To ensure curriculum coherence, it is necessary to provide very clear indicators of what learning outcomes mean. Schmidt and Prawat (2006) 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).

The first aspect of coherence requires alignment of the different elements of policy and arrangements, which include curriculum content, pedagogy, assessment, inspection, continued professional development and initial teacher education. The content of a National Curriculum cannot be considered in isolation.

In describing the rationale for the 2011–2013 review of the National Curriculum in England, the Chair of that review, Tim Oates warns about confusing the school curriculum with the national curriculum. He describes the school curriculum as the

> *…vital, lived experience of learning by individuals, carefully managed by teachers and other education professionals.*

He goes on to say that

> *if context and content are confused, then the result is a National Curriculum that includes some elements needing frequent change, alongside those that remain fundamental elements of disciplines (Oates, 2014).*

Curricula outline what students should know and be able to do at the end of a course. They do not prescribe the contexts, or list the answers to the types of questions that students should pose. This does not mean that the definition of content in a curriculum has become unimportant; it means that learning outcomes act as good organising principles for good practice in schools. The national curriculum may carry the harp[31], but the school curriculum carries the teacher's experience, knowledge of the discipline, the local setting and most importantly the students.

Teachers' experience, knowledge and professionalism cannot be underestimated; teachers know their students, and they know what works best for them. Education research can bring the theory of what is appropriate, and policy makers will implement this in a way that is logistically possible, but it is teachers who are at the heart of teaching. Teachers are the only people who can ensure curriculum coherence; it makes sense to co-construct curriculum material with teachers and learners to make the experience of change a positive and fruitful one.

3.6 Development of new specifications for senior cycle

The words *curriculum*, *syllabus*, and *specification* have different meanings in different jurisdictions. In Ireland, curriculum describes all of the complex factors that contribute to the planning of an educational program. This study uses that definition of curriculum, it includes the philosophy and rationale, as well as all of the other factors that contribute to LC science. The word syllabus describes an overview of course content, and lists what is to be taught. In Ireland, subject content used to be published as a syllabus which detailed the content of the subject or course. As part of the developments in education in Ireland, the term syllabus has been replaced by specification. The term specification describes a systematic representation of the content, described as learning outcomes. Specifications outline what students should be able to do at the end of a unit of study, and have flexibility of teaching and learning approaches built in. Typically a specification is a much more

[31] The Harp symbol in Ireland signifies that a document is an official Government publication.

comprehensive document than a syllabus. In this study, the science syllabuses refer to the current curriculum documents, implemented in 2000, the science specifications refer to the revised LC curriculum documents developed over the last 7 years and due to be implemented in 2018.

3.6.1 Learning outcomes in Irish curricula

Learning outcomes were adopted across all stages of schooling in Ireland following the national strategy for literacy and numeracy

> *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)*

The strategy further noted that curriculum developments in line with Project Maths are to adopt a "learning outcomes" design in which the expected learning outcomes to be achieved are clearly stated. Recent developments in curriculum and assessment in Ireland have included Learning Outcomes as one component of the curriculum specification. Other components include the Rationale, Aims, Objectives, Overview and Assessment. Online toolkits and guidelines for teachers are part of the Support Material component.

In Ireland, much of the debate about Learning Outcomes has emerged from within the higher and further education sectors in the context of their own curriculum/course design. The broader context of the emergence and increasing profile of the National Framework for Qualifications[32], with its intrinsic emphasis on clarity of learning outcomes as a means towards easy comparison of qualifications has also been influential. But until now, there has been relatively little focus on Learning Outcomes in the school sector at any level. While Learning Outcomes were a key feature of the rebalanced Junior

[32] Available at http://www.qqi.ie/

Certificate subject syllabuses in the 2000s, the Primary Curriculum (introduced in 1999) uses learning objectives, rather than outcomes. *Aistear*: the Early Childhood Curriculum Framework (2009) uses broad learning goals for children from birth to six years. More recently, across all school sectors there has been a significant focus on learner outcomes linked with school accountability in the last two years, as part of the process of specifying targets in School Improvement Plans (DES, 2012).

There has been a call from all of the education partners in Ireland to clarify the role of Learning outcomes in new specifications given the many possible interpretations of their role, effect and influence e.g., where teachers may view learning outcomes through the lens of high-stakes examinations, discussion has focused on the relationship between Learning outcomes and assessment; where they are viewed through the lens of school evaluation or accountability systems discussion tends to focus on the relationship between learning outcomes and the achievement of more general outcomes of schooling. At upper second level, some science and mathematics teachers indicated that the *learning* focus displaced a preferred, traditional focus on *content* which was often very detailed and tightly specified. One issue which has been raised, particularly in the sciences, is the extent to which the use of broader learning outcomes facilitates flexibility and choice in terms of *content*.

3.6.2 General sequence of development of specifications

As outlined in Chapter 1, the process of reviewing the LC science specifications began in 2006. In line with the vision for senior cycle (NCCA, 2003) the specifications were to be developed so that they provided:

- a different learning experience and school culture for senior cycle students
- a rebalanced curriculum
- different assessment arrangements

The specifications would support the kinds of innovative teaching and learning experiences envisioned for a *new look* senior cycle. Teachers and schools were to play a major part in the process of curriculum and assessment development as set out in *Leading and Supporting Change* (NCCA, 2009b). The principles and vision for senior cycle were widely agreed with by all of the education partners, and all agreed with the new directions in senior cycle education that place greater emphasis on an improved relationship between the acquisition of skills and knowledge, on learners taking more responsibility for their own learning and an improved learning culture and environment in schools. The science specifications were amongst the first to signal the move in senior cycle education in Ireland away from describing courses and syllabuses in terms of what is taught towards specifications describing what students should be able to do.

Within the NCCA, LC specifications are developed to a common template. The content is expressed as learning outcomes in which the five key skills, identified as being essential components of learning are embedded; critical and creative thinking; communicating; information processing; being personally effective; and working with others (see Section 2.3). The senior cycle template is a curriculum development tool that sets out a clear format and helps to guide the development process and helps to establish consistency across the structure of all senior cycle subjects.

In 2006 the NCCA established curriculum development groups to prepare specifications for each of the three LC subjects, biology, physics and chemistry. The curriculum development groups comprised a Board of Studies for Science and three development groups, one for each of the science disciplines. While the role of the Board of Studies was to advise on the common themes of science education and to ensure that there was consistency across the three subjects, the curriculum development groups were tasked with considering the specifics of the particular subjects. In addition to these groups, the Board for Senior Cycle oversaw all developments at senior cycle and advised on issues that are pertinent to all subjects and to the vision of senior cycle education, ensuring that there is a coherence to the developments across the senior cycle curriculum.

The development of the science curriculum and assessment specifications in Ireland were informed by a number of strands of work. Research on science education, and on education more generally, influenced the development throughout the process. International benchmarking ensured that developments in Ireland were consistent with international best practice. Working with schools throughout the process provided information on how the learning outcomes would transact in a classroom situation, and provided key insights for the development groups as they grappled to understand the relationship between *hard knowledge* and *soft skills* and the extent of the change that was envisaged. The work with schools and its impact on curriculum and assessment development is described in Chapter 6. These four elements of the work illustrated in Figure 3-20, support not only science, but are used across all development work for primary and post-primary curriculum and assessment in Ireland.

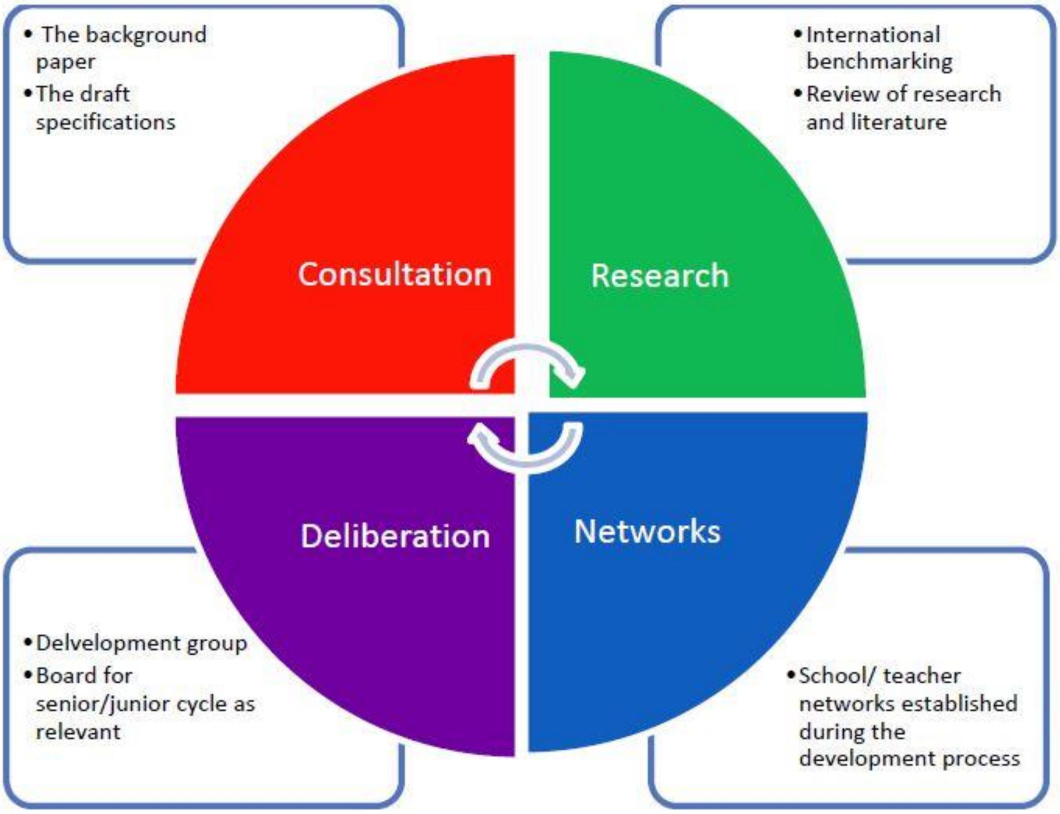


Figure 3-20 The NCCA process for developing curriculum and assessment

Curriculum development groups work to an initial brief and deliberate on what is to be included in the specifications, and on the best form of assessment for a particular course. In the case of the sciences, the development groups also had to consider the feedback and commentary from Board for Senior Cycle and the Board of Studies for Science as well as the findings from the consultation process, and the briefings provided on science education research and development.

Over the seven years of the development of the science specifications there was a total of 77 meetings of the science curriculum development groups. In addition there were three seminars for all groups, one at the beginning of the process to brief the groups and four towards the end in an effort to finalise the specifications. The timeline for the development of the final specifications is shown in Figure 3−21. The discussions at these meetings were very open and engaged, and by their nature often featured contestation around what was to be included or not. This contestation ranged from debates about *big ideas* to arguments about the wording of learning outcomes or aims. The complex work of drafting, and re-drafting by the executive between meetings had to respond to all of these debates. In the case of the LC sciences, these debates were particularly contested. Differences of opinion sometimes resulted in some nominees on the curriculum development group feeling that all of their suggestions/recommendations had not been taken on board, while others felt similarly about their, quite different opinions. While the deliberations were ongoing, the Irish Science Teachers Association (ISTA) corresponded directly with the NCCA CEO on a number of occasions when the perspective expressed by their nominee was not shared by other members of the group, nor reflected in emerging course materials. The ISTA subsequently published these letters (Hyland, 2014).

The brief for the curriculum development groups to deliver biology, chemistry and physics courses that would support inquiry-based science education for LC was not contested, but the nature of the learning outcomes that would support such an approach was. On the one hand there were those who argued that broad learning outcomes were needed that would give teachers as much flexibility as possible to pursue inquiry-based approaches and use scientific practices that would support creative approaches to teaching, learning and assessment. Others argued for tightly specified learning outcomes or lists of content that gave clear direction to teachers on what was to be taught and how, that would give teachers the certainty they needed in preparing students for high-stakes examinations. This debate lasted for the entire period of the developmental work, and it continues.

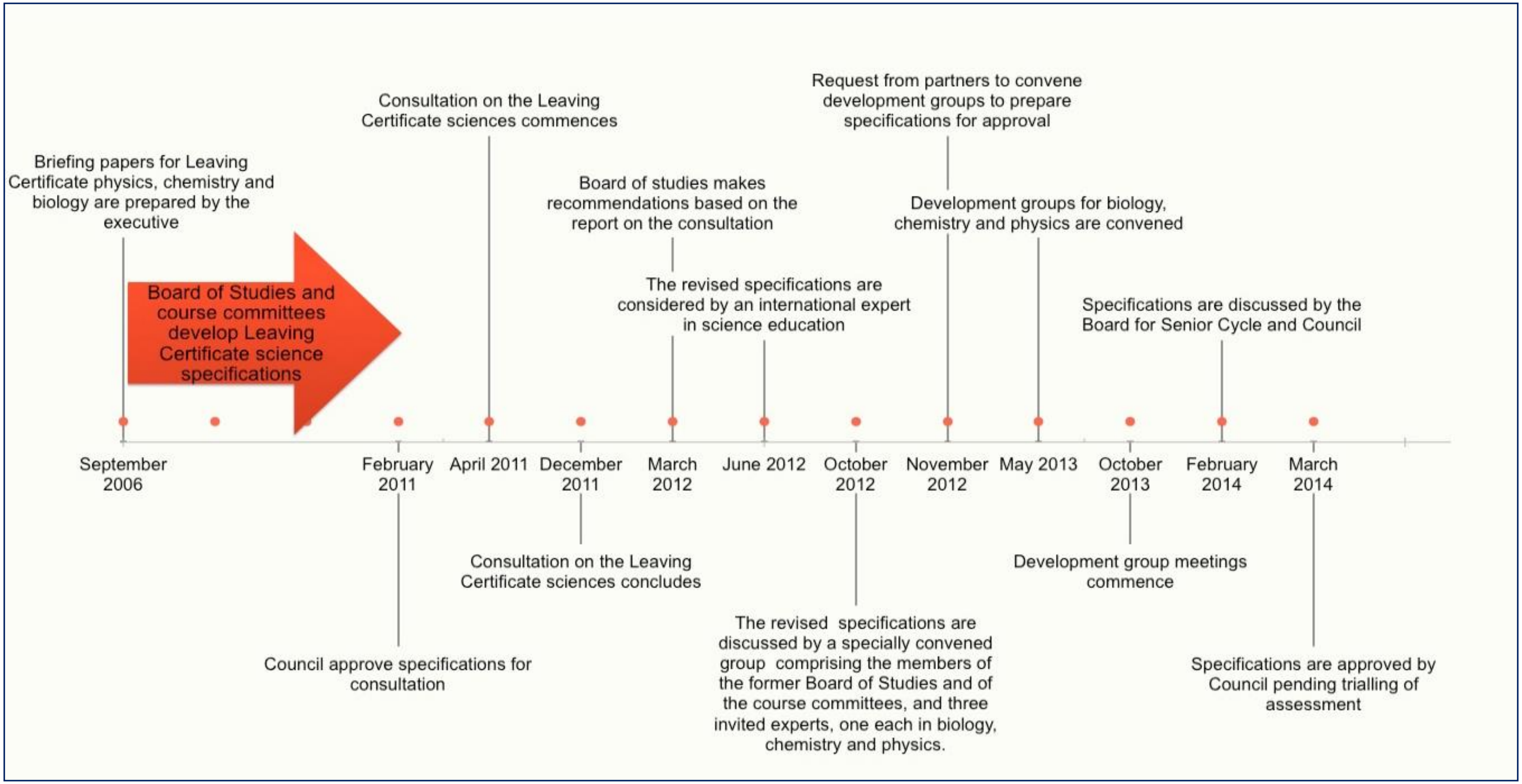


Figure 3-21 Timeline of the development of the specifications

3.6.3 Informing the debate in the development of the specifications

The brief of the development groups was to develop a specification that met all of the requirements of the new senior cycle program, that had key skills embedded and that provided a variety of opportunities for students to grow personally and intellectually through the study of science. The science learning outcomes were designed to provide opportunities for students to achieve their potential in science while engaging with the issues in science that interest and excite them.

Students should learn fundamental principles and concepts of science through participation in a wide range of skills-based activities. Active participation will enable students to connect their experiences with the theoretical concepts of science. Students will develop *information processing* and *critical and creative thinking* skills by examining patterns and relationships, analysing hypotheses, exploring options, solving problems, and applying those solutions to new contexts. They will develop skills in *working with others* as they collaborate on investigations and present and communicate their findings. In solving scientific problems students will use careful observation, thoughtful analysis, and clarity of expression to evaluate evidence, and make a clear presentation of their proposed solution. Students will learn how to research up-to-date and balanced information that they can use to develop a critical approach to accepted scientific theories and in so doing come to understand the limitations of science. Learners will develop the skill of *being personally effective* as they monitor and evaluate their own learning, and engage in metacognitive thinking.

To support such a curriculum, teachers will have to use a wide range of teaching and learning strategies. The importance of the processes of science as well as knowledge and understanding is reflected throughout the learning outcomes. Rather than being passive receivers of knowledge, students will require support to develop learning strategies that are transferable across different tasks and different subjects enabling them to make connections between all of their subjects, including science, and everyday experiences. In many cases, learners will plan, monitor, and evaluate their own learning. They will work in groups much more often and develop skills in reasoned argument, and in listening. The reality for teachers is that they will inhabit a very different learning environment that they have been used to, where they may exercise less control, but more direction.

Like all new curricula, there is a need for guidance and professional development, however, with the changes envisioned for senior cycle, the guidance and support may require an extra layer. The interpretation of learning outcomes is not always obvious, and in some ways, the language of learning outcomes is difficult to understand. If, as Daugherty says, *the construction of learning outcomes is a complex, non-linear, interacting system with the ultimate goal being a synergy that embraces curriculum, pedagogy and assessmen*t (Daugherty et al., 2012)then it is critical that teachers are given the tools to identify the elements of that complex non-linear system that contribute to the synergy. It is unrealistic to provide teachers with a set of learning outcomes without the tools to fully interpret them.

Consider the learning outcome from the new biology specification: *evaluate the arguments for and against GM crops* (NCCA, 2014) , unless teachers are provided with an insight into what the thinking behind the construction of the learning outcome was, it is unreasonable to expect them to be able to uncover the *complex, non-linear interacting system* that it represents. Without that insight, teacher's reaction may likely be:-*What arguments? What crops? What is meant by evaluate*?

The interpretation of rich, open learning outcomes, where the choice of context lies with the teacher will require a paradigm change for some teachers. It is inevitable it will not be a smooth and seamless process, and traditional support materials such as sample lesson plans and curriculum instruction material may not suffice.

To make the learning outcomes more accessible, the learning outcomes in the revised specifications have been placed within a framework. They are categorised according to knowledge domain, cognitive process domains and key skills. The framework is based on Anderson and Krathwohl's revised taxonomy of educational objectives (Anderson & Krathwohl, 2001) and is discussed in Chapter 4.

As mentioned previously, the growing emphasis on learner centred outcomes, and a move from explicit specification of content towards a more generic, skills based approach have attracted some criticism, particularly from social realists about the centrality of knowledge in teaching and learning. Priestly and Siennema (2014) carried out an analysis on two recently developed curricula, New Zealand's Curriculum Framework and Scotland's Curriculum for Excellence, both implemented in 2010. They concluded that the criticisms were partially justified in that both curricula lacked coherence about the status of knowledge. Both the New Zealand Curriculum and the Scottish Curriculum for Excellence place a strong emphasis on the importance of acquiring knowledge, but Priestly and Siennema argue that they are less clear about specifying what knowledge is to be acquired or how teachers might go about ensuring that their students might acquire the knowledge.

The tensions between a utilitarian approach to education and an education that is personally enriching is one that continues, and indeed emerged at several points during the discussions of the curriculum development groups in the development of the revised science specifications. The two are not at odds with each other. Above all the specification has to be balanced and robust, and generic skills should not be taught at the expense of domain-specific knowledge. However, the domain specific knowledge will be better and deeper if students have well developed learning skills. The two are inextricably linked. The other key skills that relate to attitudes and values should also be developed *in tandem with*, and not *as well as*, or *instead of* domain specific knowledge. In the revised specifications, the existence of an organising taxonomy provides a way of illustrating the relationship between the contributing factors of the curriculum. In carrying out an audit of the specification, the curriculum development groups were able to ensure that the range of outcomes provided an opportunity for students to develop an appropriate balance of balance of knowledge and skills and that students have the opportunity to explore an area only after they have acquired a knowledge base sufficiently large to ensure that they are unlikely to waste their time following dead-ends and irrelevancies.

The revised science specifications place a high degree of importance on knowledge, both in the overview of the specification and within the learning outcomes. The introductory statement about science education is very specific about the role of scientific knowledge and how and when it should be applied.

> *Science education provides a means by which learners can interact with the world around them and understand how scientific concepts can be used to make sense of the physical world. As learners' scientific literacy grows they will be able to make sense of the various ways in which scientific knowledge is communicated. Science is a human construct. Scientific knowledge is constructed by the sharing of ideas and by developing, refining, and rejecting or accepting these ideas. Through engagement with science learners will acquire the knowledge, skills, attitudes and values that will allow them to take informed positions on scientific issues. As well as constructing knowledge of science they will construct knowledge about science and the nature of science, including its moral and ethical dimensions. Changes in science education reflect the advances in science and technology. Emphasis is placed on society's general scientific and technological literacy and this includes an understanding of socio-scientific issues, including ethical decision making (NCCA, 2014)*

Although development of skills is central to the revised specifications for the three sciences in Ireland, throughout the specifications the knowledge that learners are expected to acquire and to demonstrate is explicitly described. However, the definition of knowledge, and the knowledge that is important for 21st century learners is important to establish. Knowledge is developing a meaning that may be different to the one that teachers and parents are currently used to. Because of this, knowledge society developments are a challenge for curriculum developers.

In *Catching the knowledge wave: the Knowledge Society and the Future of Education* (Gilbert, 2005), Jane Gilbert takes apart many long-held ideas about knowledge and education. She says that knowledge is now a verb, not a noun, something we do rather than something we have. She explores the ways that teaching and learning need to change to prepare people to participate in the knowledge-based societies of the future. According to Gilbert, learning outcomes should take account of the new meaning of knowledge. Knowledge societies no longer rely on the exploitation of natural resources; knowledge is the key resource for economic development. Learners need to encounter opportunities to go beyond learning existing knowledge and be able to do things with knowledge. To take risks and apply what they know to do something new and generate new knowledge. They also need to have opportunities to communicate their knowledge to a wide range of audiences in a wide range of contexts on their own and as part of a team.

By careful structuring of the learning outcomes to provide a balance of skills and knowledge, learners experience for themselves how ideas are developed and tested, how evidence accumulates and how new technologies transform understanding. Through this approach, students will gain knowledge of core concepts but, much more importantly, they will also gain skills in how to assess evidence critically, how information from different sources can be synthesised, and how to design experiments to test a hypothesis or how to distinguish between two alternative hypotheses. This will empower them to engage more fully with science. At a time where there is universal access to technology, it is extremely easy to find information, but much less easy to filter and assess its relevance and importance.

It is equally important to construct the learning outcomes concerned with practical activities with an appropriate balance of knowledge and skills. Practical work is important because science is an experimental subject and because, for many learners, it provides a more effective way to learn than oral or written presentation of material. The knowledge of how to use instruments and equipment, or how to perform scientific procedures is very important; learning outcomes that require that knowledge to be used in innovative and creative ways will provide practical experiences for learners that are authentic, and that add to their overall skills development and problem-solving. If learners generate and analyse their own data from self-designed investigations, they will develop mathematical skills as they analyse and interpret these data. If learners have to defend their ideas, they will be encouraged into the scientific realm of careful and rigorous testing. Not surprisingly, most teachers would argue that their job is to build an understanding of science, not to encourage criticism of it, but building in opportunities to engage in critique, argumentation and questioning not only help build students' understanding of science but also develop their ability to reason scientifically.

Getting students to think why they might be wrong requires them to think about their own knowledge, and evaluate the evidence they have to support their beliefs. This helps them in their learning efforts and helps them elaborate on their knowledge(R. Schmidt, 1993)The ability to ask good thinking questions is an important component of scientific literacy, (Millar & Osborne 1998). Learning outcomes that include argumentation and critique are at the evaluation and synthesis end of the learning taxonomy, and have been up to now omitted from science curricula in Ireland; yet it is only by engaging in these kinds of practice can students begin to understand how scientific knowledge develops – to begin to get a feel for the nature of the discipline. Moreover, engaging in argument from evidence and evaluating information require students to draw on their knowledge of science and engage in critique, evaluation and synthesis – all higher order cognitive tasks that, although challenging, also stimulate student thinking. It is this kind of activity that enables students to see that, even with their level of knowledge, it is possible to become a critical consumer of scientific knowledge and to see that there is something to be created in science.

Following the process already outlined, the final specifications for LC Biology, Chemistry and Physics was completed. It is useful to present a short extract from each specification in the next section to enable the reader to gain a sense of the specifications. The full specifications are still in draft format. In Chapter 4 the development and use of an organising framework to illustrate the specifications is discussed.

As outlined in Chapter1, the process for curriculum development involved consultation on abroad scale. There was a public consultation on the three science specifications between October 2011 and February 2012. Over 550 individuals responded to a web-based survey on the specifications and the proposed assessment arrangements. Some organisations and a number of individuals responded with detailed written submissions. A report on the consultations, and all of the submissions[33] received were published on the

[33] The individual submissions are available at
https://ncca.ie/en/Consultations/Senior_Cycle_Science/Submissions.html

NCCA website. Table 4.3 lists the Organisations who submitted responses to the consultation on Leaving Certificate sciences.

3.7 Consultation on the draft specifications

During the development process, a public consultation took place on the draft specifications. The consultation process had a number of different elements: an online questionnaire; meetings with subject associations; science teacher networks; second and third level students; representatives from STEM industries; and third level science and science education departments. The consultation responses signalled a broad welcome for revised science specifications. There was a general acceptance that throughout the courses learners should engage in inquiry with the attendant change in focus of the practical activities. Response from industry and third level were pleased to see it explicit in the specifications that as students gain knowledge and understanding of fundamental science concepts and ideas, they develop key skills and appreciate how science impacts on society. Many respondents however, stated that for this to be achievable within the 180-hour time frame, the learning outcomes would have to be limited in number, but rich in content (NCCA, 2012).

One of the main areas of feedback emerging from the consultation was a strong desire for a change in assessment. There was consensus that the assessment of the revised specifications should not reward rote learning; assessment that meets the objectives of the revised syllabuses should require higher order thinking and problem solving. It should not be predictable, but rather it should require learners to deal with unseen and unfamiliar concepts by applying science knowledge and understanding.

The following organisations provided detailed commentary on the draft revised specifications.
• Irish Science Teachers Association • Joint Submission Teachers' Union of Ireland and Association of Secondary School Teachers • The Health and Safety Authority • Engineers Ireland • Discover Science and Engineering (Managed by Forfás) • Irish Business and Employer’s Confederation and Pharmachemical Ireland • Undergraduate Science Education Students, NUI Maynooth • National Centre for Excellence in Mathematics and Science Teaching and Learning • St. Angela's College, Sligo • Microbiology Department, UCC; endorsed and supported by the College of Science, Engineering and Food Science, UCC. • Department of Science Communication, DCU • Blackrock Castle Observatory • School of Physics UCD • School of Physics NUI Maynooth • RIA Science Education Committee • Department of Chemistry NUI Maynooth • National University of Ireland, Chemistry Departments • Royal Society of Chemistry Education Division Ireland

Table 3-7 Responses to the consultation on the Leaving Certificate sciences

The draft specifications were broadly welcomed by participants in the consultation as was a welcome for the embedding of key skills and the inclusion of assessment of practical work.

> *The ISTA supports the revision of each of the syllabi and agrees that the proposed introduction of a second mode of assessment is favorable over the*

current situation where students are graded solely on a terminal examination. The value of the five key skills upon which each of the revised syllabi are based is acknowledged by ISTA members (ISTA, 2012)

The move to learning outcomes and recognition of the importance of students developing metacognition

Engineers Ireland welcomes the NCCA's proposed new curriculum in particular its approach on the delivery of the curriculum through enquiry and practical based learning. Its focus on the learning process rather than knowledge acquisition is important. This objective will be further supported by the move to a more outcome-based syllabus, which aims to give the learner the important skill of how to "self – learn". This skill and the ability to learn quickly are essential in a modern technological society, where the careers of the future lie in the creative, dynamic and innovative industries of science, technology, engineering and mathematics (Engineers Ireland 2011)

There was a general welcome for the inquiry-based approach to teaching and learning, and a call to ensure that this pedagogy is supported in assessment.

The core skills of investigation and problem solving are important skills required by industry and it is important that these are developed at second level (IBEC, 2012).

The delivery of a curriculum that promotes inquiry and develops skills as well as knowledge has the potential to provide a different learning experience for senior cycle students. DSE welcomes the proposed use of a broader range of assessment methods for learning by teachers throughout the senior cycle and of learning for certificate examinations(DSE, 2012)

Several submissions stressed the importance of using contexts from real life and industry to develop science concepts, as this will underline the relevance of science to learners.

Similar to the Project Maths curriculum and in order to provide context and relevance, it will be important that subject content is developed using examples from real life and industry (Engineers Ireland).

In order to increase motivation and interest in science, it is essential that the new curriculum emphasises connections with students' personal experiences, potential careers and their awareness of the latest scientific developments through the media (IBEC, 2012).

The two teaching unions, the Association for Secondary Teachers in Ireland, and the Teachers Union of Ireland expressed reservations about the move to broad learning outcomes.

Considerable more clarity is required in respect of what some learning outcomes will actually mean and entail in terms of the depth and breadth of study expected. In this regard in some cases the use of terms such as explain or debate is very open ended and unhelpful. Many of the learning outcomes are very broad and need to be re-worked to express more concisely giving more specific guidance to the teacher and student as to what learning is actually expected. (ASTI & TUI, 2011)

Despite the welcome for an outcomes based specification that supported deeper engagement with content, there was concern and some debate amongst the curriculum developers that echoed that of the teacher unions about the level of specification of the learning outcomes. Much of that debate came to be focused on the term *depth of treatment* which has been used in a set of Leaving Certificate syllabuses developed by the NCCA in the 1990s. Although the term was not defined by the NCCA it has generally come to mean *an indication of how much a teacher has to cover with students*. This can be content or skills. In some cases in the old syllabuses, the depth of treatment named specific examples and listed definitions to be *learned*.

The source of the debate and dispute about the nature of learning outcomes is understandable when the specification is viewed in the context of current teaching and learning practice. There is a set amount of content that students need to know, and a predictable way in which it is examined. The articulation of teachers' anxieties is documented in a report by the Irish Science Teachers Association (Hyland, 2014) in which there is strong support for maintaining the status quo

…the current syllabi are of a high standard, containing, as they do, details of the subject content, details of the depth of treatment, details of teaching activities and details of the social and applied aspects of each syllabus.

The [Irish Science Teachers] association is particularly concerned that the proposed new syllabi comprise only broad topics and learning outcomes and that they contain no indication of the depth of treatment required. (Hyland, 2014)

To support teachers and students in interpreting learning outcomes, there were calls for extensive support material to accompany the specifications. The nature of that material will need to be carefully considered. It is evident that the specification will need to be accompanied by material that clarifies what is required of students while not over-specifying what is to be taught. Action verbs with a high cognitive demand, such as debate, are appropriate for Leaving Certificate learning outcomes, but a clear description of what those action verbs mean in terms of student performance, and the types of tasks that will elicit that performance is necessary. It is important that teachers have a clear picture of how learners can apply knowledge and skills in different contexts, and demonstrate the critical thinking, and higher order skills of creativity, synthesis and analysis. Large scale curriculum change is challenging, and often falls down because of weak connections between the national curriculum, the school as an organisation and the implementation in the classrooms (van den Akker, Bannan, Kelly, Nieveen, & Plomp, 2013). To investigate the kind of material that would best support the revised specifications, a project entitled Asteroids *Impact and Craters* was carried out with teachers following the consultation. A second project *Assessment of practical science* was carried out before the consultation to provide a view of different types of practical assessment, to inform the consultation. These two projects brought teachers, policy makers and curriculum developers together to try out ways in which the curriculum would transact in classrooms, and so inform the development by practice.

3.8 Final Specifications for Science – Biology, Chemistry, Physics

Although the revised LC science specifications have less content than the current ones, although much of the traditional, content is still present. The statement of the learning is in learning outcomes, which are multi-layered descriptions of the learning process.

Extracts shown in Figures 3−22, 3−23 and 3−24 for Biology, Chemistry and Physics respectively, illustrate the differences in the presentation of the current syllabuses and the revised specifications. The same broad content area is presented for both versions to allow a comparison to be made.

In the current syllabuses, the practical work that students are expected to do is listed at the end of each unit as mandatory experiments. In the revised specification, the practical work is generally, but not always, open-ended. See for example, Figure 3−25.

In addition, the revised specifications each have a unit on scientific practice Table 4.1 The unit is common to all three specifications. The scientific practices apply to all of the content in the subsequent units. Planning for teaching and learning should include opportunities for students to engage in scientific practices as they learn fundamental science concepts. Scientific methods, research, interpretation of data and use of evidence and argument in evaluating information are central to both the practical activities and the theoretical concepts in the revised specifications. A new aspect of LC science is that students undertake an extended scientific investigation in which they research a topical issue and plan and undertake a practical investigation related to the issue. The students prepare and present a scientific communication describing the research question, methodology, results and conclusions of their open-ended investigation.

CELL METABOLISM			
Sub-unit and topic	**Depth of Treatment**	**Contemporary Issues and Technology**	**Practical Activities**
Cell metabolism	Definition of metabolism		
Sources of energy	References to solar energy and cellular energy		
Enzymes	Definition of enzymes-reference to their protein nature, folded shape and roles in plants and animals. Special reference to their role in metabolism Effect of pH and temperature on enzyme activity	Bioprocessing with immobilized enzymes. Procedure, advantages and use in bioreactors	Investigate the rate of pH and of temperature on the rate of one of the following: amylase, pepsin or catalase activity Prepare one enzyzme immobilisation and examine its application

Students learn about	***Students should be able to***
Proteins and enzymes	▪ explain catalysis ▪ describe how protein shape and folding affect enzyme activity ▪ *investigate the effect of substrate concentration or enzyme concentration, or temperature, or pH on the rate of an enzyme-catalysed reaction

Figure 3-22 Section from current syllabus and revised biology specification

STOICHIOMETRY, FORMULAS AND EQUATIONS			
Content	Depth of Treatment	Activities	STS
States of matter (I class period)	Motion of particles in solids , liquids and gases Diffusion. Grahams law not required)	NH_3 and HCL, ink and water, smoke and air	
Gas Laws (7 class periods)	Boyle's Law Charles's Law Gay –Lussac's law of combining volumes Avogadro's law Combined gas law $\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2} = constant$	Calculations not required Simple calculations including correction of gas volumes to s.t.p.(units:Pa. cm^3,K).	Boyle's air pump

Students learn about	***Students should be able to***
Gas laws	▪ use the kinetic theory model to explain the solid, liquid and gaseous states of matter and the changes that occur during melting and vaporisation (non-mathematical treatment) ▪ describe and discuss the assumptions of the kinetic theory of gases and the evidence for this theory (Brownian motion) ▪ explain what is meant by an ideal gas and account for any deviation of real gases from ideal gas behaviour ▪ *investigate the relationships between pressure, volume and temperature of a gas ▪ explain Boyle's Law and Charles' Law in terms of the kinetic theory ▪ solve quantitative problems using: ▪ Boyle's and Charles' laws ▪ **combined gas law (general gas law)** ▪ **equation of state for an ideal gas** ▪ (units: Pa, m^3, K)

Figure 3-23 Section from current syllabus and revised chemistry specification

Light			
Content	Depth of Treatment	Activities	STS
REFLECTION			
Laws of Reflection		Demonstration using ray box or laser or other suitable method	
MIrrors	Images formed by plane and spherical mirrors. Knowledge that $\frac{1}{f}=\frac{1}{u}+\frac{1}{v}$	Real-is-positive sign convention. Simple exercises on mirrors by ray tracing or use of formula	Practical uses of spherical mirrors. Concave, Convex Dentists, Supermarkets Floodlights, Driving mirrors projectors

Students learn about	**Students should be able to**
2.1 Reflection	▪ *investigate experimentally the relationship between an object and its image in a plane mirror ▪ *investigate experimentally the relationship between object distance, image distance and ▪ focal length ▪ magnification, for a curved mirror ▪ construct diagrams that illustrate reflection at plane and curved mirrors ▪ use experimental and theoretical techniques to analyse and solve problems on reflection at plane and curved mirrors ▪ discuss uses of plane and curved mirrors ▪ explain how an echo is formed and discuss echo imaging using ultrasound as a diagnostic device in medicine

Figure 3-24 Section from current syllabus and revised physics specification

Current syllabus

- Preparation of a standard solution of sodium carbonate.
- Standardisation of a hydrochloric acid solution using a standard solution of sodium carbonate.
- Determination of the concentration of ethanoic acid in vinegar.
- Determination of the amount of water of crystallisation in hydrated sodium carbonate.
- A potassium manganate (VII)/ammonium iron (II) sulfate titration.
- Determination of the amount of iron in an iron tablet.

  i) An iodine/thiosulfate titration.

  ii) Determination of the percentage (w/v) of hypochlorite in bleach.

Revised specification

- prepare a primary standard solution of sodium carbonate and use this solution to standardise a solution of hydrochloric acid and subsequently that of a sodium hydroxide solution
- accurately determine the concentration of particular analytes by titration:

  (i) monoprotic acids

  (ii) potassium manganate (VII)

  (iii) iodine-thiosulfate

  (Balanced equations given)
- prepare stock solutions of a coloured compound and use them to construct a calibration curve with the aid of a colorimeter; use the calibration curve to determine the concentration of a solution of this compound

Figure 3-25 Comparison of practical work for volumetric analysis between the current chemistry specification and the revised one.

Students learn about	Students should be able to
1.1. Hypothesising	▪ use observations as the basis for formulating a hypothesis ▪ apply their knowledge and understanding of science to develop arguments or draw conclusions related to both familiar and unfamiliar situations ▪ compile and interpret data or other information gathered from print, laboratory, and electronic sources (including web sites), to research a topic, solve a problem, or support an opinion ▪ make predictions and generalisations based on available evidence
1.2 Experimenting	▪ identify variables and select appropriate controls ▪ design, manage and conduct practical investigations and also investigations based on secondary data ▪ collect, organise, interpret, present and analyse primary and secondary data with and without the use of technology ▪ describe relationships (qualitatively and/or quantitatively) between sets of data, recognising the difference between causation and correlation ▪ distinguish between statistical and systematic uncertainty and identify appropriate methods to reduce this ▪ recognise uncertainty as a limitation of the process of measurement and appreciate the difference between accuracy and precision ▪ conduct an open-ended investigation
1.3 Evaluating evidence	▪ critically examine the scientific process that was used to present a scientific claim ▪ appreciate the limitations of scientific evidence ▪ make judgments and draw informed conclusions arising from their own and others' investigations and consider the reliability and validity of data ▪ make predictions on the behaviours of systems based upon interpretation of numeric, graphic and symbolic representations ▪ evaluate the ethical issues embedded in scientific decision-making processes

Students learn about	Students should be able to
1.4 Communicating	▪ communicate the procedures and results of investigations by displaying evidence and information in various forms, including flow charts, tables, graphs, and laboratory reports ▪ discuss, debate, reflect on and critically evaluate the outcomes of investigations, their own and others ▪ read and evaluate scientific explanations of everyday phenomena in books, websites, promotional literature, popular science magazines, etc.

Table 3-8 Unit I scientific practices, revised specifications in biology, chemistry and physics.

3.9 Conclusion

Overall, what is evident from the international comparison is that there are key features common to 21st century curricula. Development of key competences/skills is a fundamental theme underpinning each of the curricula examined. Although the knowledge and understanding of science concepts and theories is important, what learners are able to do with that knowledge and understanding tends to be equally, and increasingly, important. Another common theme is that of learners developing scientific habits of mind through working and behaving like scientists. The importance of learner engagement in practical science is another common feature. In each curriculum, the practical and process skills of science are assessed, although there is no consensus on how that assessment happens. In each case the details of the course, provided in the specification/syllabus, is further exemplified, described and linked to assessment through some form of additional support material. Although it is acknowledged that assessment of the kinds of skills that learners develop by carrying out practical work is problematic, its assessment continues to be a feature of curricula at upper second level.

The review of the literature and of the curricula in other jurisdictions indicates that the use of learning outcome, embedding of key skills, reduction in content and focus on higher order cognitive skills in the revise specifications is justified, and is in line with international best practice. It is also appropriate to include a second, practically based component of assessment to align with assessment of science internationally.

Key to the success of the use of rich open learning outcomes is development of a strategy to ensure curriculum coherence. Curriculum coherence is necessary to ensure every student has access to high quality teaching and learning that is aligned with the National curriculum. It is equally important that teachers have a way of *checking in* and enduring that they are on task. New curricula provide the opportunities for teachers to be innovative; being innovative involves taking risks. It is easier to take risks if you can check that what you are doing is falling within the broad ideals and parameters of the National Curriculum. The next chapter will discuss the new curricula for Leaving Certificate science in Ireland, using an organising framework for learning outcomes was developed based on Anderson and Krathwohl's revised taxonomy (Anderson & Krathwohl, 2001). The organising framework categorised learning outcomes based on cognitive demand, knowledge dimension and key skills. By using the organising framework, teachers will be able to gain insights into the thinking that was used in the construction of the outcomes. This will support them to plan for rich and varied teaching that has an appropriate balance of skill, knowledge and cognitive demand.

4 Framework development and analysis in Leaving Certificate sciences

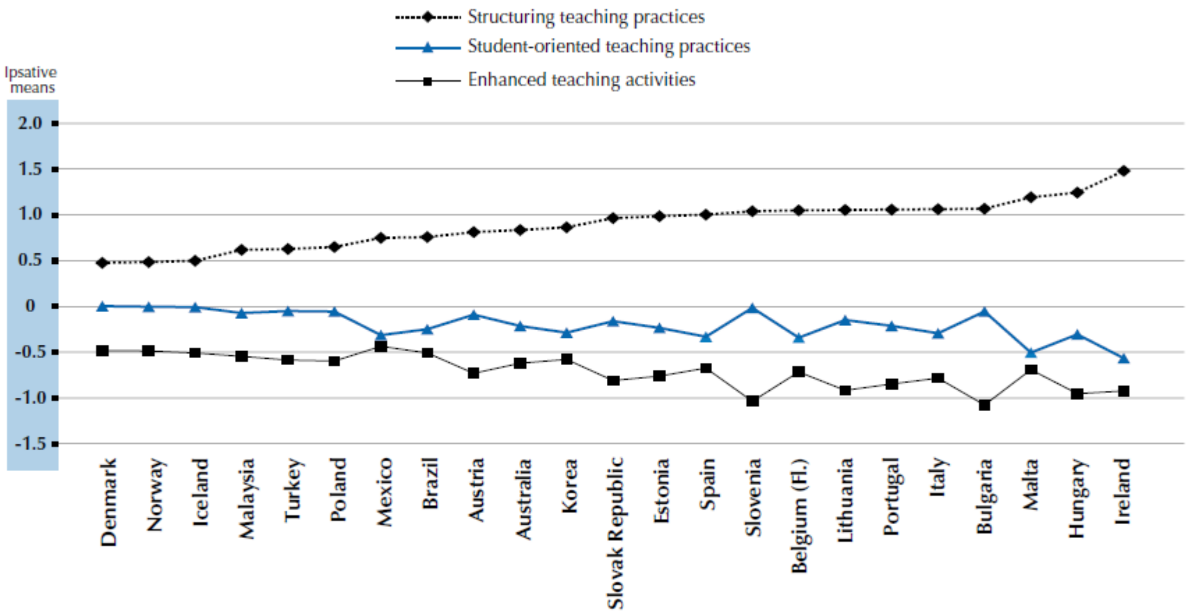
In previous chapters, the background to inclusion of key skills and competencies in curricula for second-level students has been discussed. How these skills and competencies are set out in curricula and communicated has been shown though a comparison of curriculum documentation from a number of countries. The expression of new curricula as *learning outcomes* has been justified both from research evidence and from international practice. This chapter provides an overall description of the directions for change at senior cycle, and the process of curriculum review, including the structures involved. An organising framework was developed that was used at points through the development process to track the development of three Leaving Certificate (LC) science specifications. Within this chapter, the organising framework developed is discussed in terms of the data it provided for an overview of the specifications and how it was used to support curriculum development, and describes a study in which teachers were asked to use the framework to critically analyse their understanding of learning outcomes.

4.1 Background and context for developing frameworks for curriculum and assessment

A move to more student-centered curricula that focus on skills development as well as knowledge-building will require teachers to develop innovative teaching and learning strategies that involve discussion and collaborative group work. This will be a significant challenge for teachers. There is some evidence from subject inspections in post-primary science that although some teachers try to include innovative teaching methods, and less structured teaching approaches, the dominant teaching methodology is teacher led, highly structured and traditional. Inquiry-based learning, when used, is as an add-on rather than as a consistent methodology[34]. This is backed up by research carried out by

[34] Inspection reports available from http://www.education.ie/en/Publications/Inspection-Reports-Publications/

the OECD about the range of teaching methodologies most often used by teachers across the OECD countries. Irish second-level teachers reported that they used structured teaching practices much more frequently than student oriented or enhanced activities (OECD, TALIS Database, 2009 cited in . Schleicher (ed.) (2012), and in fact came at the bottom of the list for use of innovative teaching practices (see Figure 4-1).



Countries are ranked by the relative frequency with which they engage in structuring teaching practices, student-oriented teaching practices and enhanced activities. So, teachers in Denmark adopt the different practices to a fairly similar degree, while teachers in Ireland use structuring teaching practices much more than they do either student-oriented practices and enhanced activities.
Source: OECD, *TALIS Database.*

Figure 4-1 Approaches to teaching. Country mean of ipsative scores (OECD TALIS Database 2009)

The reliance on structured, teacher-led teaching is consistent with the current emphasis in Leaving Certificate syllabuses on defined knowledge to be acquired. There is scant attention paid to the development of skills, and even less attention paid to attitudes, values, and metacognition. The finding in TIMSS and PIRLS 2011 indicated that Irish students performed less well on indicators relating to reasoning in mathematics and science (Eivers & Clerkin, 2011). For many teachers, adapting to the methodologies espoused by the revised specifications will require a change in mind-set, and in some cases, a change in fundamental beliefs about education and curriculum.

To support the development of the revised specifications, groups of teachers collaborated to explore and exemplify how *innovative, enhanced, student-oriented practices* could be included in their normal teaching, whilst at the same time maintaining the rigor of the discipline knowledge. They also noted the way assessment could measure the extent to which students achieved the learning outcomes, as well as how it could help to operationalize the learning outcomes.

4.2 Organising Framework

In this section the development and use of an organisation framework to audit and track the development of the specifications is discussed.

The organising framework was developed to help curriculum developers to assemble learning outcomes, and to recognise the key skills that were embedded in them. This framework can then be used by teachers to interpret the learning outcomes, and recognise the embedded skills as they plan for teaching, learning and assessment.

Anderson and Krathwohl (Anderson & Krathwohl, 2001)provide six reasons for placing learning outcomes within a framework, as follow:

- It makes teachers look at the learning from the students' point of view. If teachers are expected to conceptualise what students are expected to do with the knowledge, they will be more mindful of providing the correct methodology. They will have to ask themselves questions about the type of knowledge. If it is factual, then memory will suffice, if is conceptual, they may have to apply it to something, and they will have to do something with it. Students are often asked to grapple with very difficult concepts, at a low cognitive level. For example, learning a sequence of chemical reactions (factual knowledge) without the necessary conceptual knowledge underpinning the reactions is probably of no use to the student, and will be quickly forgotten. If teachers have to ask themselves about when knowledge is metacognitive, they have a chance of really getting inside the student's head. It may prompt them to provide contexts and opportunities for a student to develop learning strategies and practice metacognition.

- It helps teachers to consider different possibilities and achieve higher order objectives. The addition of the metacognitive domain to the taxonomy is important as it adds the *learning to learn* dimension which is very empowering to students and reminds teachers to include opportunities for students to consider the learning process as well as the outcomes.
- Categorisation within the framework allows teachers to see the relationship between knowledge and the cognitive process.
- It makes assessment easier. When learning outcomes are categorised in a taxonomy, teachers do not have to approach every learning outcome as a unique entity. They will develop teaching, learning and assessment strategies for the broad divisions of the taxonomy. It is easier to write assessment items that align with the learning outcomes, because it is clear what the learners are expected to be able to do.
- Categorisation can help to ensure curriculum coherence. It makes it possible to check whether sections of the curriculum are aligning with the overall objectives.
- A framework helps to make sense of the language of education. It brings a conformity to curricula, which when used across a range of subjects helps to provide a picture of the overall learning over a range of subjects.

In considering which taxonomy to use, several taxonomies were considered, and each had its merits. For example, the SOLO taxonomy (Structure of Observed Learning Outcomes) would have worked very well, the progress between the levels is implicit, and for students' interpretation of learning outcomes probably would have been a better fit for the framework (Biggs & Tang. 2007). Anderson and Krathwohl's revision of Blooms taxonomy (Anderson & Krathwohl, 2001) was chosen because of teachers' familiarity with the language of Bloom' s taxonomy as it is used with teachers in professional development, and a vocabulary around Bloom has developed. Also, it was considered important to include the knowledge dimension to help with the unpacking of learning outcomes. Anderson and Krathwohl's revision of Bloom's Taxonomy of Educational Objectives (Anderson & Krathwohl, 2001) uses a simple categorisation based upon the structure of the learning outcome. The taxonomy examines each learning outcome on two dimensions, the knowledge dimension and the cognitive dimension, the knowledge dimension is divided into factual, conceptual, procedural and metacognitive knowledge while the cognitive dimension is characterised into 6 sub headings as shown in Figure 4-2**.** Each dimension is expanded in Tables 4−1 and 4−2, showing the detail of what is meant by each dimension.

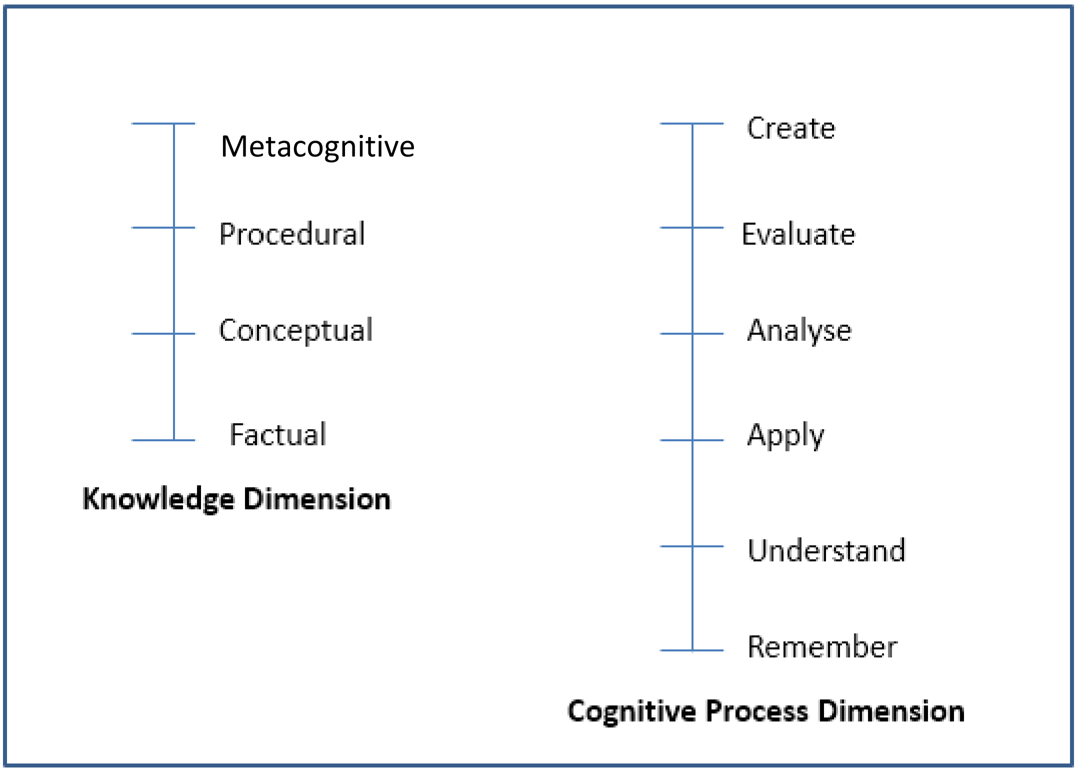


Figure 4-2 Two dimensional taxonomy (Anderson and Krathwohl 2001)

Each learning outcome contains a verb and a noun, the verb generally describes the intended cognitive process, the noun generally describes the knowledge that students are expected to acquire or construct. Consider the example of the learning outcome from the Biology specification: *students should be able to evaluate the arguments for and against GM crops.* The verb *evaluate* indicates the cognitive process, it is at level C5 on the taxonomy, according to *making judgements based on criteria or standards*. The noun phrase, *arguments for and against GM crops* tells us what the knowledge dimension is. It falls into knowledge of principles and generalisations, or of theories models and structures, so it can be classified as conceptual knowledge (K2).

Consider another learning outcome from the chemistry specification: *students should be able to predict the trends in physical properties (b.p., solubility in water) of straight chain hydrocarbon molecules (up to C10) using relative molecular mass and intermolecular forces to rationalise predictions.* Applying the taxonomy, predicting, also falls into category C5, evaluating- making judgements based on criteria. The noun phrase *trends in physical properties* etc. is knowledge of classifications and categories, which is conceptual knowledge, K2. Both learning outcomes are very different, but despite the different subject matter, both are grounded in *conceptual knowledge*, both require students to engage in the process *evaluate.* Once we understand the meaning of conceptual knowledge, and the meaning of *evaluate*, we know a great deal about both of these learning outcomes. Placing a learning outcome into a framework increases our understanding of the outcome. Once the learning outcomes have been defined in terms of the framework, it enables educative curriculum material to be developed that targets the knowledge and the cognition rather than the content. In this way, teachers can develop teaching and learning material in a context of their choice, confident that the material is aligned with the learning outcome. The understanding gained from placing the outcomes into a framework can be used to plan for learning, for teaching, for assessment and for alignment.

K1 FACTUAL KNOWLEDGE – the basic elements students must know to be acquainted with a discipline or solve problems in it	
• Knowledge of terminology • Knowledge of specific details and elements.	- Technical vocabulary, scientific symbols - Major natural resources, reliable sources of information
K2 CONCEPTUAL KNOWLEDGE – The interrelationships among the basic elements within a larger structure that enable them to function together.	
• Knowledge of classifications and categories • Knowledge of principles and generalizations • Knowledge of theories, models, and structures	- Periodic table, classification of living organisms - Theory of evolution, Hooke's law - - - Theory of evolution, structure of the atom
K3 PROCEDURAL KNOWLEDGE – How to do something, methods of inquiry, and criteria for using skills, algorithms, techniques, and methods	
• Knowledge of subject- specific skills and algorithms • Knowledge of subject-specific techniques and methods • Knowledge of criteria for determining when to use appropriate procedures	- Skills used in measuring, use of instruments and equipment - Experimental techniques, scientific method - Criteria used to determine when to apply a procedure involving Newton's second law, criteria used to judge the feasibility of using a particular method to estimate population size
K4 METACOGNITIVE KNOWLEDGE – Knowledge of cognition in general as well as awareness and knowledge of one's own cognition	
Strategic knowledge Knowledge about cognitive tasks, including appropriate contextual and conditional knowledge Self-knowledge	- Knowledge of outlining as a means of capturing the structure of a unit of subject matter in at textbook, knowledge of the use of heuristics - Knowledge of the cognitive demands of different tasks - Knowledge of one's own personal strengths and weaknesses awareness of one's own knowledge level

Table 4-1 The knowledge dimension. Adapted from Anderson & Krathwohl, 2001

Cognitive processes	Alternative names	Definitions and examples
C I Remember – Retrieve relevant knowledge from long-term memory		
Recognising	Identifying	Locating knowledge in long-term memory that is consistent with presented material (e.g., identify species acting as acids and bases in chemical processes)
Recalling	Retrieving	Retrieving relevant knowledge from long-term memory (e.g., recall a definition)
C2 Understand – Construct meaning from instructional messages, including oral, written, and graphic communication		
Interpreting	Clarifying, paraphrasing, representing, translating	Changing from one form of representation (e.g. numerical) to another (e.g. graphical) (e.g. plot a graph)
Exemplifying	Illustrating, instantiating	Finding a specific example or illustration of a concept or principle (e.g. Give examples of homogeneous catalysis)
Classifying	Categorizing, subsuming	Determining that something belongs to a category (e.g. concept or principle) (e.g. Classify elements as solids liquids or gas)
Summarising	Abstracting, generalizing	Abstracting a general theme or major point(s) (e.g. Write a short summary of the events portrayed in the media or described in a scientific text)
Inferring	Concluding, extrapolating, interpolating, predicting	Drawing a logical conclusion from presented information (e.g. In interpret data, infer scientific principles from examples)
Comparing	Contrasting, mapping, matching	Detecting correspondences between two ideas, objects and the like (e.g. compare nervous and hormonal coordination)

Cognitive processes	Alternative names	Definitions and examples
Explaining	Constructing models	Constructing a cause-and-effect model of a system (e.g. Explain the possible causes of climate change)
C3 Apply – Carry out or use a procedure in a given situation		
Executing	Carrying out	Applying a procedure to a familiar task (e.g. apply a formula to determine velocity.
Implementing	Using	Applying a procedure to an unfamiliar task (e.g. Use Newton's Second Law in previously unseen situations in which it is appropriate)
C4 Analyse – Break material into its constituent parts and determine how the parts relate to one another and to an overall structure or purpose		
Differentiating	Discriminating, distinguishing, focusing, selecting	Distinguishing relevant from irrelevant parts or important from unimportant parts of presented material (e.g. Distinguish between relevant and irrelevant information in a scientific contextual situation)
organising	Finding coherence, integrating, outlining, parsing, structuring	Determining how elements fit or function within a structure (e.g. Structure evidence in a scientific description into evidence for and against a particular scientific explanation)
Attributing	Deconstructing	Determine a point of view, bias, values, or intent underlying presented material (e.g. Determine the point of view of the author of a piece of scientific evidence in terms of his or her political perspective)
C5 Evaluate – Make judgments based on criteria and standards		
Checking	Coordinating, detecting, monitoring, testing	Detecting inconsistencies or fallacies within a process or product; determining whether a process or product has internal consistency; detecting the effectiveness of a procedure as it is being implemented

Cognitive processes	Alternative names	Definitions and examples
Critiquing	Judging	Detecting inconsistencies between a product and external criteria , determining whether a product has external criteria, determining whether a product has external consistency; detecting the appropriateness of a procedure for a given problem
C6 Create– Put elements together to form a coherent or functional whole; reorganize elements into a new pattern or structure		
Generating	Hypothesizing	Coming up with alternative hypotheses based on criteria (e.g. generate hypotheses to account for an observed phenomenon)
Planning	Designing	Devising a procedure for accomplishing some task (e.g. plan an open ended investigation)
Producing	Constructing	Inventing a product (e.g. design and build a measuring instrument for a specific purpose)

Table 4-2 The cognitive process dimension. Adapted from Anderson & Krathwohl, 2001

The final framework now allows us to position each learning outcome in terms of the knowledge dimension, the cognitive process dimension and the embedded key skill. The framework consists of a glossary of action verbs for learning outcomes, the adapted learning taxonomy (as shown in Tables 4−1 and 4−2) and the NCCA key skills framework (Appendix 1). At key stages through the development process each of the specifications was audited using this framework. These audits guided the work of the development groups and signalled the kind of teaching, learning and assessment examples from the school networks that were needed to support the development groups in their deliberations.

4.2.1 Applying the framework to track the development of the specifications

The rationale for applying the framework to quantify each of the dimensions of the learning outcomes was to provide an overall picture across the three specifications at key points during the development. (The learning outcome action verbs become command terms when used in assessment, and the same framework applies. This will be discussed further in Chapter 5). An example of how the framework was applied to the learning outcomes is provided in Figure 4 −3. For each learning outcome, it was categorised across the three dimensions, thus allowing a collective map of the overall input of each dimension to the overall specifications. It should be noted that while there is always some argument/discussion around the assignment of any particular outcome to a particular dimension, the decision was made based on the intended learning as envisaged by the researcher.

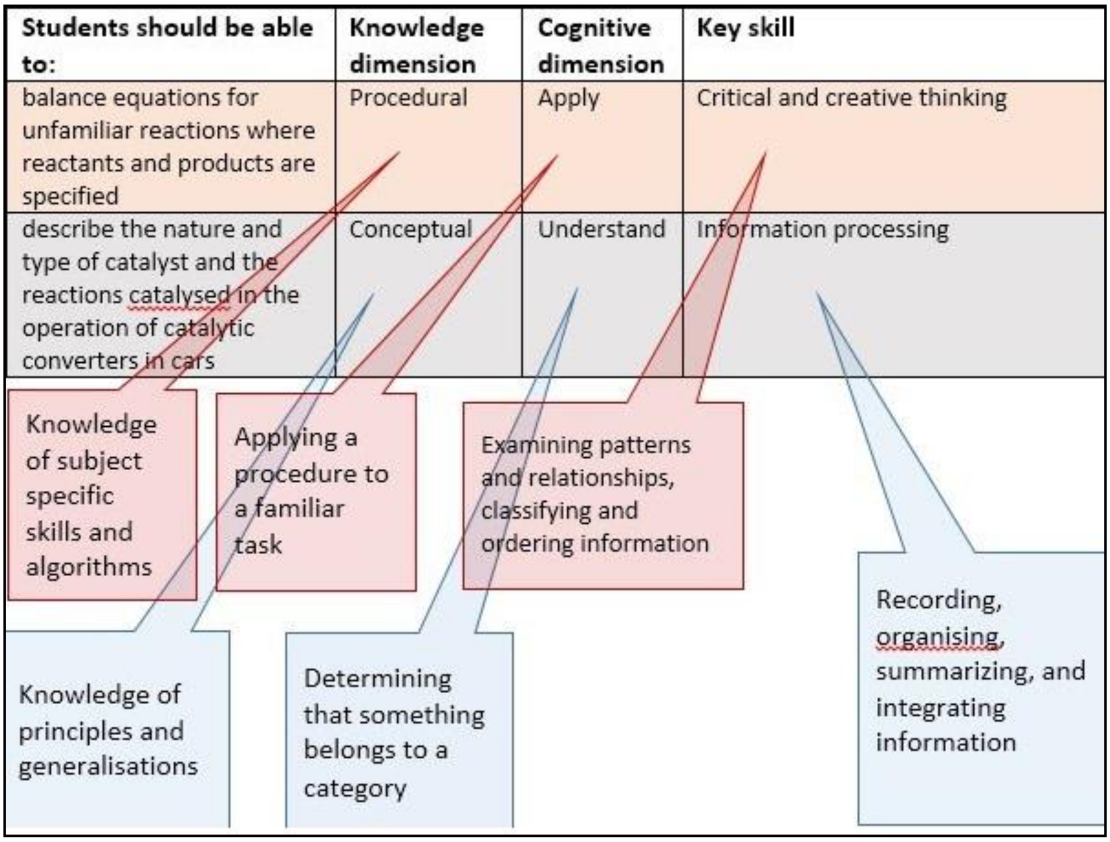


Figure 4-3 Applying the framework to learning outcomes

The NCCA executive used this framework to audit the revised science specifications at four critical points during their development (see Figure 3−20 for the timeline). The categories were assigned to each specification following discussion and agreement between the researcher and the Education Officer for each of the subjects.

The four stages where the framework audit was carried out were: The first draft specification in 2008; just after changes were made following consultation in 2012 and again at the approval for implementation stage in 2014. The results of these audits informed the discussions and debates around the balance of knowledge and skills, and the direction of the work with schools that was required to operationalise the learning outcomes (further discussed in Chapter 6).

The organising framework for learning outcomes was applied to the three specifications at three significant points. 2008, 2012 and 2014. Those points in the development were chosen for the following reasons:

2008: To base line the first specifications

2012: Between 2008 and 2012 three pieces of work were carried out with schools to support the development groups in their work. Teachers worked with the NCCA to generate examples of teaching learning and assessment that showed: possibilities for practical assessment; inquiry based learning; and teaching and learning of fundamental science topics to develop key skills and enhance the learning. This work influenced the deliberations of the development groups. Also, the consultation had taken place; the 2012 specifications include the changes made in response to the consultation.

2014: The 2014 specifications are the final specifications that are approved for implementation. Whilst there was not unanimous agreement by all of the partners about each of the learning outcomes, the 2014 specifications were the culmination of 7 years of deliberations by 6 committees involving approximately 77 meetings. Each committee has an average of 20 members, so to say the discussion was extensive is an understatement. Whilst some opposing views remained somewhat entrenched, the presence of examples in the form of video and assessment added greatly to the discussion.

4.2.2 Results of audits on specifications

The graphs below Figures 4−4, 4 −5, 4 −6 for chemistry, physics and biology respectively, show the spread of each of the dimensions of the framework over the three audits. This analysis is not considered quantitative; the purpose of the framework is as a development tool, not as an analysis tool or a diagnostic tool. The results are therefore not a critique of one specification over another, or indeed of the specifications in general; however they do reflect the progress of the development of each of the specifications.

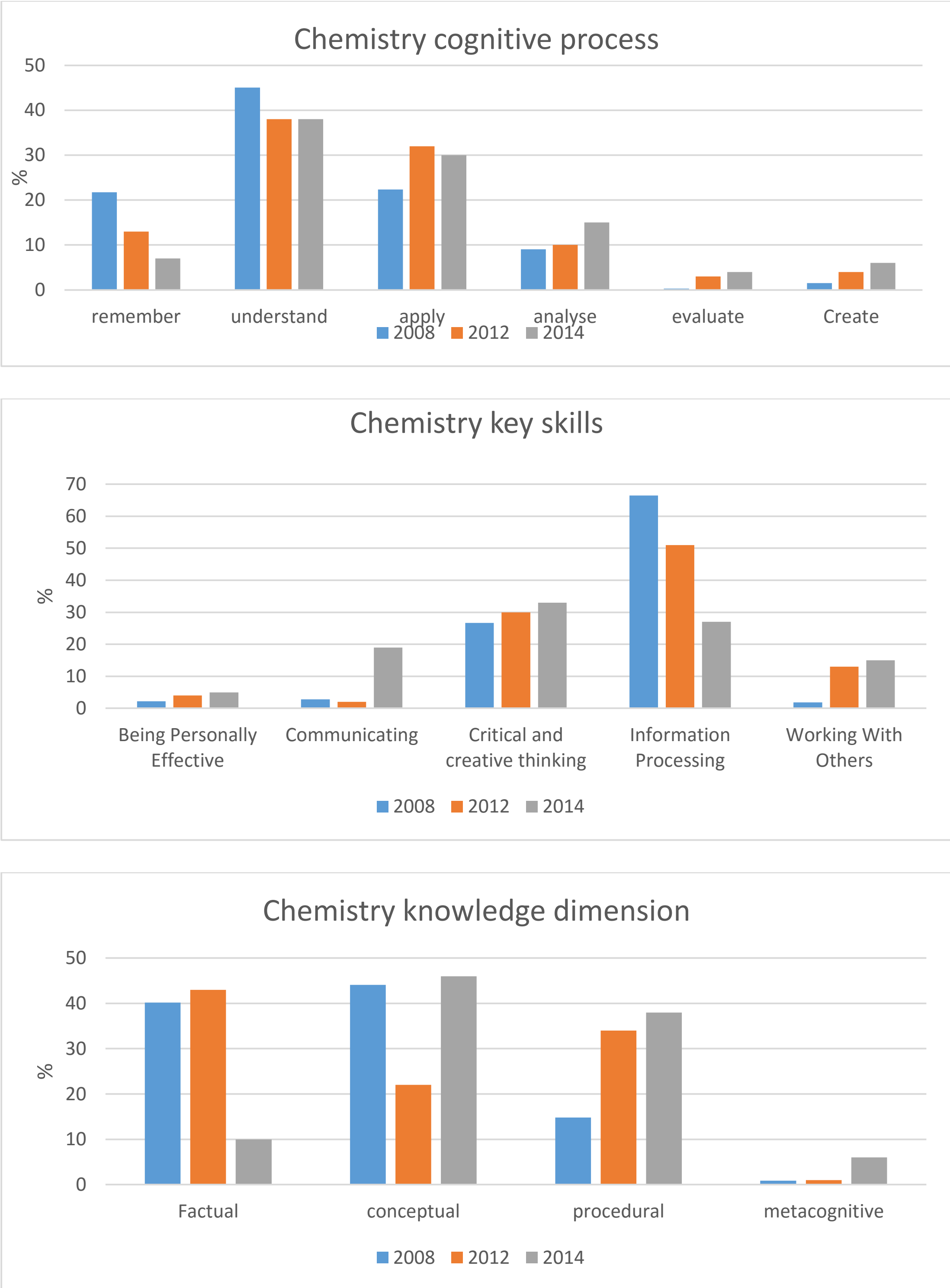


Figure 4-4 Comparison of chemistry learning outcomes 2008-14

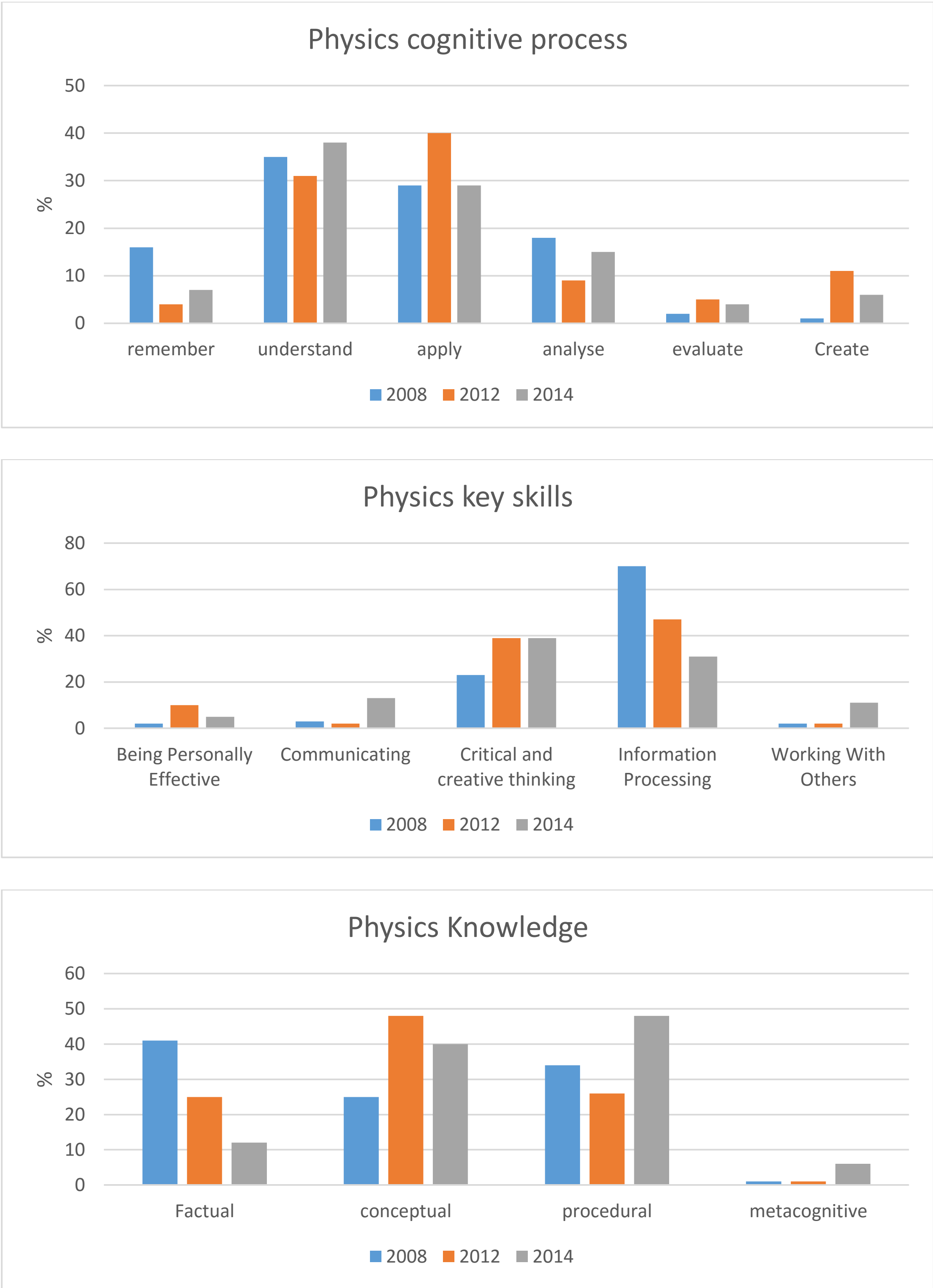


Figure 4-5 Comparison of physics learning outcomes 2008-14

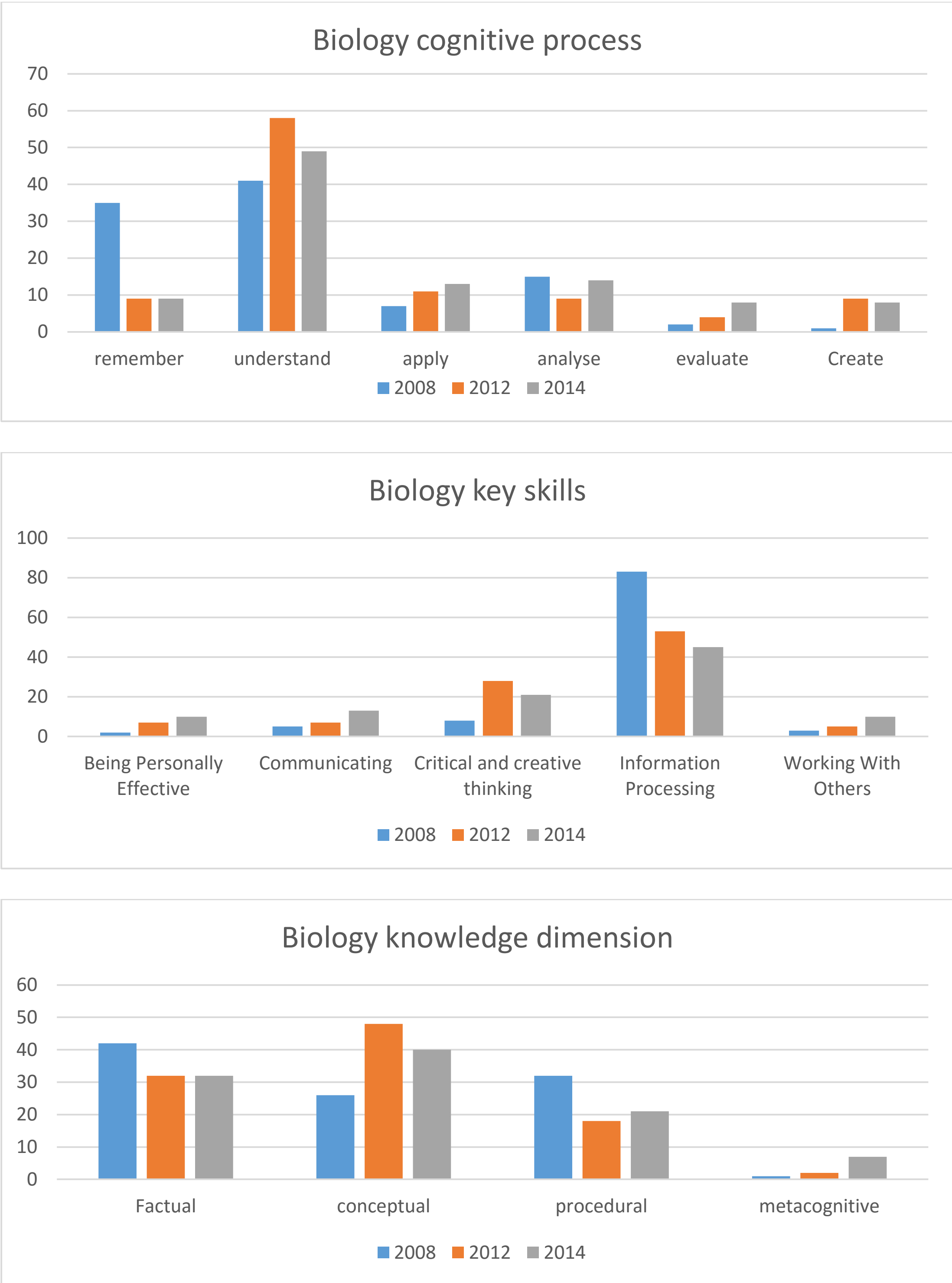


Figure 4-6 Comparison of biology learning outcomes 2008-14

Noteworthy points from each of the subjects are discussed below.

Across each of the three specifications, there is a general change in learning outcomes over time to higher cognitive processes and knowledge dimensions. All of the key skills are evident in each of the specifications to varying degrees.

Chemistry

The learning outcomes in the chemistry specification were the most highly contested of the three subjects. There was a strong feeling throughout the process from a significant number of group members that highly atomised learning outcomes were preferable to outcomes in which the learning and the content were not very tightly specified. The first draft of the specification that was drawn up had 468 learning outcomes, with no less than 52 definitions. The Board of Studies singled out the chemistry specification as being the one that was least aligned to the aim and objectives following the consultation.

That being said, the three graphs, Figure 4−4, show a shift towards a spread of learning outcomes that are reflected in the aim and objectives. As with the other two subjects, an over representation of information processing skills are, to a small extent, replaced by critical and creative thinking. As with physics, an effort was made to include skills that developed communication skills.

From Figure 4−4 it can be seen that some learning outcomes that were at the *remember and understand* end of the cognitive process dimension were replace with those that required learners to apply their knowledge and understanding and to evaluate, synthesise and create. As might be expected, this is mirrored by a similar re-distribution away from factual knowledge to conceptual and procedural and metacognitive knowledge.

Physics

It was noted by Board of Studies after the consultation that the physics specification was the one most aligned of the three to the aim and objectives. As with biology, a large number of outcomes that were predominantly concerned with information processing gave way to those where the skills of critical and creative thinking were embedded. Of note in physics was the reaction of the course committee to the lack of the skills of communication and working with others in the initial audit. As a result the committee made continued efforts throughout the development to include learning outcomes that required learners to communicate, e.g. debate, and working with others, engage in work that required collaboration. In Figure 4−5 the fluctuation of the learning outcomes in the apply category is notable. When the committee revisited some of these outcomes, there was a sense that many related to application of formulas to known situations, and might have been miscategorised. This started a deep discussion about what *derive* should mean, and resulted in a effort to include outcomes where learners would have to apply their physics understanding to previously unseen situations. This aspect will be further discussed in Chapter 6, as this discussion led directly to some of the work with schools.

Biology

From Figure 4−6 it is clear that the skill of information processing is by far the most prominent skill embedded in the biology learning outcomes, however as the specifications developed from 2008 to 2014 the skills became more distributed across the learning outcomes. There is evidence that information processing in some instances gave way the skills of critical and creative thinking, communicating and being personally effective.

Of note in particular is the effect that this audit had on the discussions about what content could be left out of the specification. There was general agreement that the specification had far too many learning outcomes and was very content heavy, but there was reluctance to omit traditional content that had always been there. The decisions on what to remove from the specification was made based on the embedded skills and the cognitive level rather than on *favourite* content. At that stage much of the content that was traditionally learned off by heart, such as the bones of the skeleton and the ultrastructure of the kidney were omitted in favour of content that learners could engage with at a deeper level, such as some new higher order outcomes in genomics.

The reduction in numbers of lower order learning outcomes at this stage explains the marked decrease in the outcomes classified in the *remember* category in Figure 4−6. This category was highest in 2008 and lowest in 2014. Many of the lower order learning outcomes that were highly specified were changed to more open-ended higher order outcomes which resulted in the increase in the percentage of outcomes requiring learners to create and evaluate.

4.3 A snapshot of teachers' interpretation of the Learning outcomes framework

The organising framework was developed to support curriculum development (as discussed in previous section) but also in curriculum coherence, i.e. help teachers to have a shared understanding of learning outcomes, and to ensure in as far as possible that their understanding was consistent with the interpretation of the curriculum developers.

It is important to appreciate the different dimensions of curriculum:

- The intended or specified curriculum has a focus on the aims and content of what is to be taught – that is, the curriculum as it is planned by the curriculum developers.
- The implemented or enacted curriculum relates to what is actually put in place for students in schools. The implemented curriculum includes local interpretations of the formal curriculum documents. When learning outcomes are rich and broad, the alignment of the intended and implemented curriculum becomes critical to achieve curriculum conformity.
- The experienced curriculum refers to the learning actually experienced by students. The learners interaction with the curriculum is mediated by the teacher, an organising framework will provide a way to keep the message consistent.

It is commented on that the implemented curriculum is often quite different from the intended curriculum, i.e. the curriculum as it transacts in classrooms is often at variance with what the curriculum developers intended (Pinar et al., 1995,van den Akker, 1998). Different perspectives contribute to curriculum from policy makers, researchers and practitioners. Pepin and Nieven refer to this as a trilemma of different worlds (Figure 4-7) (Pepin & Nieven , 2013). To maximise curriculum conformity different perspectives should be managed. That is not to say that different perspectives are not necessary, and in many cases essential, however, in as far as possible, the *big ideas* of curriculum should be consistent.

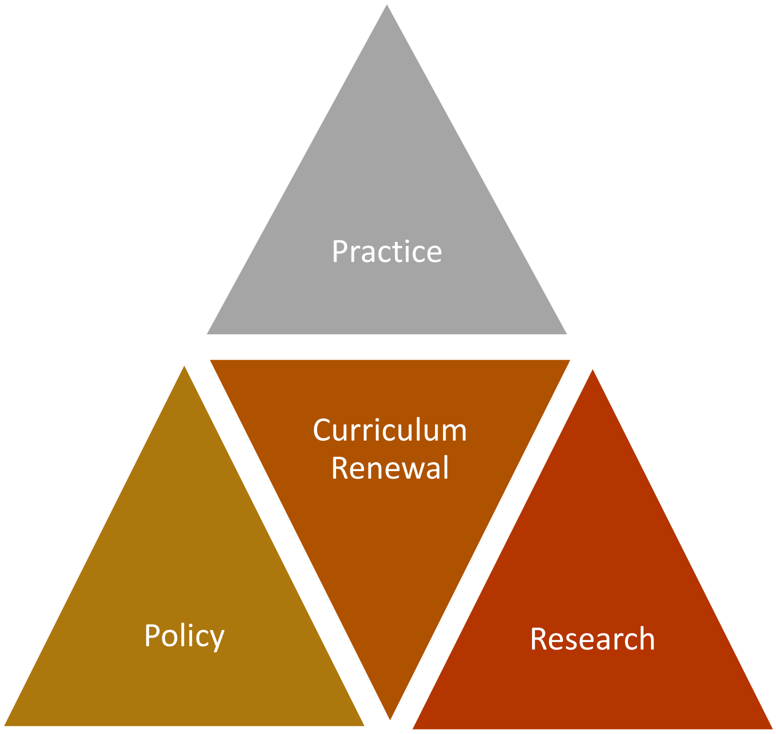


Figure 4-7 Trilemma of different worlds (Pepin & Nieveen, 2013)

To get a snapshot of the extent to which the curriculum developers' interpretation of learning outcomes in the revised science specifications matches teachers' interpretations, a group of teachers was asked to use the organising framework to classify a selection of learning outcomes according to the knowledge dimension, the cognitive process dimension and the predominant embedded key skill(s). Their classification was then compared with that allocated to the learning outcomes by the researcher based on the development group discussions.

4.3.1 Teacher Selection and instruction

During the six years of curriculum development many teachers had contributed in various ways and at various levels to the work of the NCCA. Many teachers had made contact at various points during the process asking to contribute, or asking for information about the developments. Another group of teachers who had at some stage asked for information to help them with their research projects. All of these teachers (approx. 100) were invited to participate in this exercise and 23 agreed. It is noteworthy that the teachers who were invited to do the exercise were all teachers who, at some level, had expressed an interest in, or worked with some aspect of the developments, though not at the level of curriculum development.

It was considered that anonymity was important, as teachers may have been reluctant to identify themselves in case they *got it wrong*. In hindsight, it would have been useful to identify teachers as their reasons for selecting the various dimensions could have been probed further. Without direct knowledge of teachers' reasons for making particular selections, the discussion of the results is based on personal opinion. Hence, a web-based survey format was used[35].

The teachers were directed to a specially designed website that encompassed the web survey and accompanying background documents:

The website provided a background to the research, and:

- A glossary of learning outcome action verbs from the specifications (Appendix 3)
- A taxonomy for learning teaching and assessing based on Anderson and Krathwohl's revision of Bloom's taxonomy (given in Table 4.1 and 4.2)
- The NCCA key skills framework (Appendix 1).

Teachers were asked to use the information from the three documents to designate a knowledge dimension, a cognitive process dimension and a key skill to 15 learning outcomes randomly selected from the revised chemistry specification.

The learning outcomes were presented in a web-based form, each learning outcome had four selection boxes, where teachers chose the category in each case, (Figure 4-8). There were two options for selection of key skills, teachers were asked to select one predominant skill, but were given the option of selection two.

[35] Available at: https://sites.google.com/site/loscience35/home.

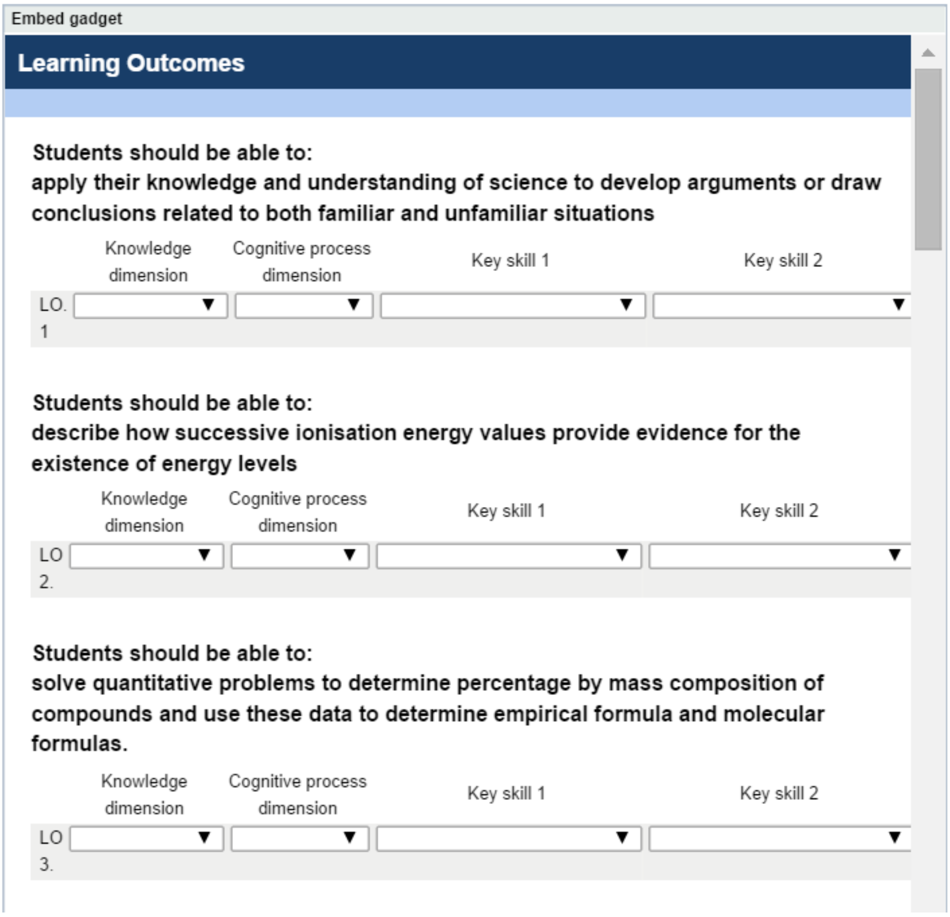


Figure 4-8 Learning outcomes web-based form.

For each learning outcome, teachers were asked to select a knowledge dimension, a cognitive process dimension, and the predominant embedded key skill or skills (Figure 4.9).

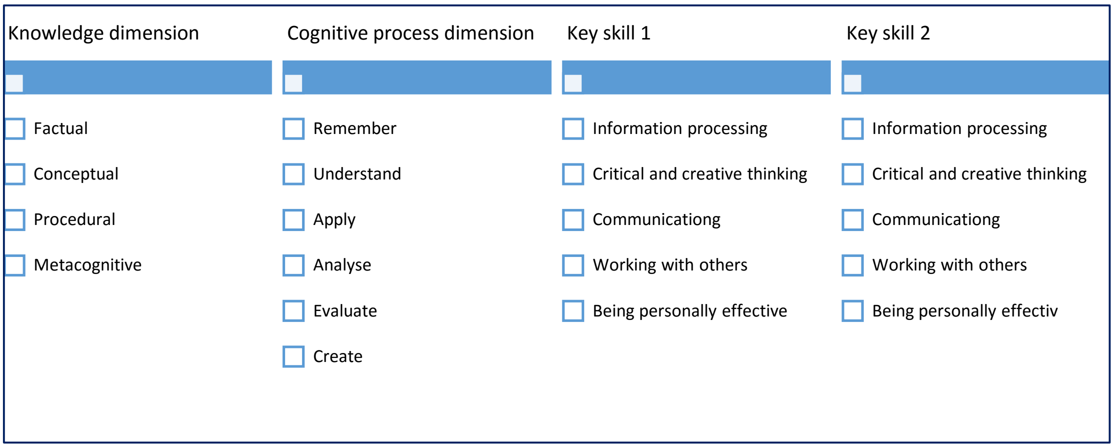


Figure 4-9 Selection menus

Fifteen learning outcomes were selected at random from the chemistry specification[4] and were presented to the teachers in random order (Table 4 -3):

LO	Students should be able to:	Type
1	describe the separation of crude oil by fractional distillation into useful fractions	**Recall information**
2	describe how successive ionisation energy values provide evidence for the existence of energy levels	**Describe a known concept**
3	explain what is meant by: catalyst, catalyst poison, enzyme, and use appropriate examples to explain the terms homogenous catalysis and heterogeneous catalysis	**Explain the meaning of terms or concepts**
4	apply knowledge of electrochemistry to explain how corrosion occurs and outline the principles that underpin four different processes of prevention	**Apply knowledge and understanding to explain a scientific phenomenon**
5	use Brønsted-Lowry theory to identify species acting as acids and bases in chemical processes (limited to aqueous solutions)	
6	identify the location of the electrons within the bonds of hydrocarbons and explain how this determines whether the molecules are stable or reactive and if addition or substitution reactions are favoured	
7	solve quantitative problems to determine percentage by mass composition of compounds and use these data to determine empirical formula and molecular formulas	**Solve quantitative problems**
8	solve quantitative problems involving balanced equations using the mole concept to determine: (i) numbers of moles and masses of reactants and products (ii) volume of gases (iii) exact stoichiometric amounts (iv) limiting reagent (v) percentage yields (vi) numbers of molecules or atoms	

LO	Students should be able to:	Type
9	solve quantitative problems using: (i) Boyle's and Charles' laws (ii) combined gas law (general gas law) (iii) equation of state for an ideal gas (units: Pa, m^3, K)	
10	use experimental data to determine average and instantaneous rates of reaction	**Interpret scientific data**
11	observe and record continuous and line emission spectra of various light sources (prescribed practical activity)	
1 2	apply their knowledge and understanding of science to develop arguments or draw conclusions related to both familiar and unfamiliar situations	**Apply knowledge and understanding to develop arguments**
13	debate the relationship between global temperature and the proportion of carbon dioxide in the atmosphere	**Debate a scientific issue**
14	Students should be able to: investigate the effect of concentration, temperature and catalysis on the rate of a reaction (techniques may include gas evolution, colorimetry and precipitation) (prescribed practical activity)	**Carry out an open -ended investigation**
15	Students should be able to: investigate the temperature changes during evaporation of a range of organic liquids to illustrate the effect of (i) intermolecular forces and (ii) molecular mass (specified practical activity)	

Table 4-3 Randomly selected learning outcomes

The learning outcomes that were randomly generated were checked to see if they and an appropriate range of skills, knowledge and cognitive demand.

4.3.2 Results

For analysis, the fifteen learning outcomes were grouped into similar types and numbered as LO1-15 (Table 4-3). The knowledge dimension and the cognitive process dimension and the key skills are abbreviated as shown in Table 4 - 4.

No.	Knowledge	No.	Cognitive process	No.	Key skill
K1	Factual	**C1**	Remember	**S1**	Information processing
K2	Procedural	**C2**	Understand	**S2**	Critical and creative thinking
K3	Conceptual	**C3**	Apply	**S3**	Communicating
K4	Metacognitive	**C4**	Analyse	**S4**	Working with others
		C5	Evaluate	**S5**	Being personally effective
		C6	Create		

Table 4-4 Survey Number system

Tables 4-5 to 4-10 show the categories as selected by the teachers for each LO. Also each table shows a highlighted box indicating the classification of each LO by the researcher and the % agreement indicates the proportion of the teachers' whole selection agreed with that of the researcher.

LO1, LO2 and LO3 recall, describe and explain. Table 4-5 summarises results for the three LOs and show:

Knowledge: There was good agreement on the knowledge dimension of these outcomes. Teachers recognised that describing separation of crude oil is a recall of factual knowledge (K1), whereas describing *how* ionisation energies provide evidence for energy levels requires conceptual knowledge (K2). A number of teachers interpreted the *how* as factual knowledge.

Cognitive process: Teachers recognised that the recall (C1) in outcome LO1 was of factual knowledge, while the conceptual knowledge of outcome 2 and 3 required understanding (C2).

Key skills: Teachers recognised the key skill of information processing (S1) in all three. This suggests that learning outcomes at this level are clearly understood by teachers.

Communication was selected by a number of teachers; this may reflect the teacher intention in terms of pedagogy rather than the LO itself.

1. *describe the separation of crude oil by fractional distillation into useful fractions*							
	1	2	3	4	5	6	% agree
Knowledge	21	2	0	0			91
Cognitive process	21	1	1	0	0	0	91
Key skill	23	0	0	0	0	0	100
2. *describe how successive ionisation energy values provide evidence for the existence of energy levels*							
	1	**2**	**3**	**4**	**5**	**6**	
Knowledge	6	17	0	0			73
Cognitive process	4	19	5				83
Key skill	21	2					96
3. *explain what is meant by: catalyst, catalyst poison, enzyme, and use appropriate examples to explain the terms homogenous catalysis and heterogeneous catalysis*							
	1	2	3	4	5	6	
Knowledge	4	19	0	0			82
Cognitive process	0	20	3				87
Key skill	16	0	6				69

Table 4-5 Analysis of Learning outcomes LO1, LO2, LO3 (describe and explain).

LO4, LO5 and LO6: Apply knowledge and understanding to explain a scientific phenomenon Table 4-6 summarises results for the three LOs and show:

Knowledge: The classification of knowledge varied in these outcomes. The disagreement was whether the knowledge was conceptual or procedural. In outcome LO4, and LO6 teachers classified the knowledge as conceptual (K3), even though students have to do something with the information, so it is better classified as procedural (K2). On the other hand, teachers classified outcome LO5 as procedural knowledge (K2), rather than conceptual (K3) even though students are classifying species based on their understanding.

Cognitive process: Most of the teachers classified the three outcomes in this dimension in agreement with the researcher. It is of note that the distinction between *understand* (C2) and *apply* (C3) was correctly applied across the three outcomes, suggesting that these teachers had a good understanding of the cognitive process at this level even when it isn't immediately obvious. Learning outcome LO5 on first reading appears to require application, but in reality, it is drawing a logical conclusion from presented information rather than applying understanding to come to a conclusion.

Key skills: The most striking observation in this category is the number of teachers who classified outcome LO6 as information processing (S1) rather than critical and creative thinking (S2). This is interesting because it suggests that they have not thought about the processes involved in this learning outcome. Students will not be able to find the information; they will have to generate it based on their understanding of chemistry. It could be argued that students could research the position of the electrons in a particular molecule, but they should be able to identify the location of electrons in molecules that they will not have come across before, therefore requiring critical and creative thinking skills.

4. apply knowledge of electrochemistry to explain how corrosion occurs and outline the principles that underpin four different processes of prevention							
	1	**2**	**3**	**4**	**5**	**6**	**% agree**
Knowledge	0	17	6	0			26
Cognitive process	0	0	23	0	0	0	100
Key skill	2	21	0	0	0		91
5. use Brønsted-Lowry theory to identify species acting as acids and bases in chemical processes (limited to aqueous solutions)							
	1	2	3	4	5	6	% agree
Knowledge	4	4	15	0			17
Cognitive process	0	18	5	0	0		78
Key skill	16	7	0	0	0	0	70
6. identify the location of the electrons within the bonds of hydrocarbons and explain how this determines whether the molecules are stable or reactive and if addition or substitution reactions are favoured							
	1	**2**	**3**	**4**	**5**	**6**	**% agree**
Knowledge	8	15	0	0			0
Cognitive process	8	1	13	0	1		56
Key skill	19	4	0	0	0		17

Table 4-6 Analysis of Learning outcomes LO4, LO5, LO6 Apply knowledge and understanding to explain a scientific phenomenon

LO7, LO8 and LO9: solve quantitative problems Table 4-7 summarises results for the three LOs and show:

Knowledge: Teachers correctly identified the knowledge as procedural (K2). The most common other choice was conceptual knowledge (K3), possibly because they saw solving problems as an intellectual process, which it is, and associated this with conceptual knowledge.

Cognitive process: The majority of teachers recognised solving quantitative problems as requiring application, carrying out a procedure in a given situation (C3).

Key skill: The key skill of critical and creative thinking (S2) was correctly selected by most teachers.

7. *solve quantitative problems to determine percentage by mass composition of compounds and use these data to determine empirical formula and molecular formulas*							
	1	**2**	**3**	**4**	**5**	**6**	**% agree**
Knowledge	0	5	18	0			78
Cognitive process	0	0	21	2	0	0	91
Key skill	5	18	0	0	0		78

8. *solve quantitative problems involving balanced equations using the mole concept to determine: (i) numbers of moles and masses of reactants and products (ii) volume of gases (iii) exact stoichiometric amounts (iv) limiting reagent (v) percentage yields (vi) numbers of molecules or atoms*							
	1	**2**	**3**	**4**	**5**	**6**	**% agree**
Knowledge	0	5	18	0			78
Cognitive process	0	0	20	3	0	0	87
Key skill	5	18	0	0	0		78

9. solve quantitative problems using: (i) Boyle's and Charles' laws (ii) combined gas law (general gas law) (iii) equation of state for an ideal gas (units: Pa, m^3, K)							
	1	**2**	**3**	**4**	**5**	**6**	**% agree**
Knowledge	0	5	18	0			78
Cognitive process	0	0	21	2	0	0	91
Key skill	5	18	0	0	0		78

Table 4-7 Learning outcomes LO7, LO8 and LO9 solve quantitative problems

LO11 and LO12: interpret scientific data. Table 4-8 summarises results and show:

Knowledge: There was good correlation of the knowledge dimension as conceptual (K3). One notable exception was the selection of conceptual knowledge by 6 teachers in LO 11. This is puzzling, as both outcomes arise out of practical activities.

Cognitive process: Teachers correctly identified these outcomes as belonging to the apply dimension (C3).

Key skills: Teachers correctly identified these outcomes as having critical and creative thinking skills (S2) embedded, although it could be argued that, as they are practical activities, working with others (S4) is equally valid. Interestingly no teachers selected that, even though they had the opportunity to select a second skill.

10. use experimental data to determine average and instantaneous rates of reaction							
	1	**2**	**3**	**4**	**5**	**6**	**% agree**
Knowledge	0	0	23	0			100
Cognitive process	0	0	19	4	0	0	82
Key skill	2	21	0	0	0		91

11. *observe and record continuous and line emission spectra of various light sources (prescribed practical activity)*							
	1	**2**	**3**	**4**	**5**	**6**	**% agree**
Knowledge	1	6	16	0			69
Cognitive process	0	1	18	4	0	0	78
Key skill	7	16	0	0	0		69

Table 4-8 Outcomes LO10-LO11 Interpret scientific data

Learning outcomes LO12, LO13: **apply knowledge and understanding to develop arguments.** Table 4-9 summarises results for the three LOs and show:

Knowledge: For outcome LO12, there was general agreement about the knowledge, but it was interesting to note that 2 teachers placed it in the metacognitive dimension (K4), which is also valid. It could be argued that to develop arguments students require metacognitive strategies, however, metacognition is arguably more correct for outcome LO13 where students engage in debate. Only 7 of the 23 teachers recognised the metacognitive aspect of LO13.

Cognitive dimension: There was little agreement about the cognitive dimension in outcome LO12, yet good agreement in outcome LO13. Teachers did not recognise the need for students to make judgements based on criteria or standards in application of understanding to develop arguments, yet they did when the term debate was used.

Key skills: As the learning outcomes become higher order in terms of cognitive process, as in these two outcomes, it is less easy to assign a particular skill, and all or any are valid. It is encouraging to see that 11 teachers selected being personally effective as the main skill developed through debate (S5).

12. apply their knowledge and understanding of science to develop arguments or draw conclusions related to both familiar and unfamiliar situations							
	1	2	3	4	5	6	% agree
Knowledge	0	6	15	2			65
Cognitive process	0	0	18	3	2	0	78
Key skill	1	6	8	0	8		26

13. debate the relationship between global temperature and the proportion of carbon dioxide in the atmosphere							
	1	**2**	**3**	**4**	**5**	**6**	**% agree**
Knowledge	0	3	13	7			
Cognitive process	0	1	0	5	14	3	
Key skill	0	1	5	6	11		

Table 4-9 Outcomes LO12-LO13 Apply knowledge and understanding to develop arguments

LO14, and LO15 open-ended investigations. Table 4-10 summarises results for the three LOs and show:

Knowledge: all teachers recognised that these outcomes required procedural knowledge (K3)

Cognitive process: most teachers place investigation at either level C5 evaluate or level C6 create.

Key skill: It is interesting to note that teachers viewed the skill of working with others (S4) as the main skill in these outcomes, yet they did not see them as the main outcomes in the more prescriptive experimental work. This could indicate that they distinguish between physically carrying out work in the company of others in an experiment, and working with others to plan, carry out and evaluate an investigation.

14. *Students should be able to: investigate the effect of concentration, temperature and catalysis on the rate of a reaction (techniques may include gas evolution, colorimetry and precipitation)*							
	1	**2**	**3**	**4**	**5**	**6**	
Knowledge	0	0	23	0			100
Cognitive process	0	0	0	3	6	14	61
Key skill	0	1	0	17	5		22
15. *Students should be able to: investigate the temperature changes during evaporation of a range of organic liquids to illustrate the effect of (i) intermolecular forces and (ii) molecular mass*							
	1	**2**	**3**	**4**	**5**	**6**	
Knowledge	0	0	23	0	0		100
Cognitive process	0	0	0	3	6	14	61
Key skill	0	1	0	17	5		22

Table 4-10 Outcomes LO14-LO15 Open-ended investigation

4.3.3 Discussion of the results

This exercise was not in any way an evaluation of either the framework or of teachers' understandings of the learning outcomes. For example, it is arguable that any one of the five key skills can be attributed to each learning outcome, depending on how and in what context it is taught, and that is a good thing. The comparison was to see if there was a general agreement between teachers and the researcher in relation to interpretation of learning outcomes, to get an indication of where discrepancies should be signalled, and to see if an organising framework such as the one used here would be useful in helping teachers to understand learning outcomes and could be used in teacher professional development.

As it stands, the level of agreement on the categorisation of the outcomes is remarkable. There are a number of possible points for discussion that emerge from this short exercise. Firstly, where the learning outcome closely resembled something that students currently do, there was a tendency for teachers to categorise the outcome as it is currently taught, rather than according to the taxonomy of the revised specification. As the order of the outcomes become higher, for example debate an issue, the greater the level of discrepancy. That is to be expected, and does not necessarily mean that the teachers have misinterpreted the outcomes; what is highlights is that the *learning intention* (as oppose to how to teach it) must be made very clear where there is an outcome that can be interpreted in multiple ways.

4.4 Framework for assessment

The revised taxonomy (Anderson & Krathwohl, 2001) offers a two dimensional view of learning, the knowledge dimension and the cognitive process dimension. The six categories of cognitive process are hierarchical, going from knowing at the lowest level to creating at the highest level. The four categories of the knowledge dimension lie along a continuum, from concrete (factual) to abstract (metacognitive) (see Figure 4−4). The conceptual and procedural categories overlap in terms of abstractness, with some procedural knowledge being more concrete than the most abstract conceptual knowledge. Applying a similar taxonomy to assessment provides a visible connection between curriculum, pedagogy and assessment. The combination of the knowledge dimension with the cognitive process dimension allows measurement of outcomes that are more complex than simply pieces of discrete content.

Many researchers have developed assessment frameworks for various purposes and four of these frameworks are presented below.

4.4.1 Edwards and Dall'Alba's scale of cognitive demand

The Edwards and Dall'Alba's scale of cognitive demand was developed originally as an instrument for analysing secondary science lessons, materials and evaluation programs in Australia (Edwards & Dall’Alba, 1981). The scale categorised cognitive demand in four dimensions: Complexity, Openness, Implicitness and Level of Abstraction (Figure 4−10). Six levels of demand were defined within each dimension by a list of phrases and command words that could be used to describe the processes students were required to carry out in the task (Figure 4−11). The scale was developed to be readily utilisable by classroom teachers. It was planned that the instrument would allow teachers to analyse the cognitive demand suggested by the learning objective, made by the learning task, and evaluated by the evaluation instrument. This would provide internal consistency with respect to these three curricular components. The level of cognitive demand is determined by the interaction of all of its dimensions. The dimension requiring the highest level of cognitive demand was the principal factor in determining the overall level.

Cognitive demand	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6
Complexity	Simple operations	Require a basic comprehension	Understanding, application or low level analysis		Analysis and/or synthesis	Synthesis or evaluation
Openness	No generation of new ideas		Limited generation of ideas	Generation of ideas from a given data base	Generation of ideas which are original for the student	Highly generative
Implicitness	Data are readily available to the senses	Data to be operated on are given	A large part of the data is given but requires generation of the final outcome		Data are not available in a readily useable from - must be transformed	Require a view of the entity in question as part of a more extensive whole
Level of Abstraction	Deals with concrete objects or data stored in the memory	Predominantly deals with concrete objects or images		Corresponds to concrete-abstract transition	Abstract	Highly abstract

Figure 4-10 Levels of cognitive demand (Edwards and Dall'Alba1981)

Key words	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6
	Recall or memorise specifics Assimilate information Simple measurement Observe Simple comparison Simple recording Follow a simple set of instructions Observe with discrimination	Recall or memorise procedures, processes, rules of principles Simple classification Demonstrate use of equipment Understand a direct, physical model Translate, Summarise	Relate Develop an operational definition or simple concept Simple application Simple extrapolation Compare on stated criteria Identify discriminating characteristics	Internalise a concept Apply a rule of principle Classify Simple hypothesising Complete an experimental design Understand a model of abstraction	Construct a model or other representation Generate relevant criteria Extrapolate Generalise Hypothesise Isolate variables Design an experiment or piece of equipment Isolate inferences or assumptions Integrate	Develop or explain a concept of an abstraction Link a model with reality Assess the impact Evaluate

Figure 4-11 Key words for levels of cognitive demand (Edwards and Dall'Alba1981)

4.4.2 The CRAS scale of demand

Hughes et al. used the Edwards and Dall'Alba scale to develop a tool for gauging the demands of GCSE and A Level exam questions (Hughes, Pollitt, & Ahmed, 1998).

	1	2	3	4	5
Complexity The complexity of each component operation or idea and the links between them.	←	Simple operations (i.e. ideas/steps) No comprehension, expect that required for natural language No links between operations	↔	Synthesis or evaluation of operations Requires technical comprehension Makes links between operations	→
Resources The use of data and information.	←	All and only the data/information needed is given	↔	Student must generate the necessary data/information.	→
Abstractness The extent to which the student deals with ideas rather than concrete objects or phenomena.	←	Deals with concrete objects	↔	Highly abstract	→
Strategy The extent to which the student devises (or selects) and maintains a strategy for tackling and answering the question	←	Strategy is given. No need to monitor strategy. No selection of information Required. No organisation required.	↔	Student needs to devise their own strategy and monitor the application of their strategy. Must select content from a large, complex pool of information. Must organise how to communicate response.	→

Figure 4-12 The CRAS scale of demand (Hughes et al., 1998)

During that work, they recognised that although examiners are generally able to recognise and agree on the overall level of demand that assessment items make on students in terms of skills, knowledge, understanding and application, however, they are not good at explaining it. Hughes and her colleagues developed their tool to provide a common language for examiners so that they could discuss and have a shared understanding of the demands being made on candidates. The tool also built awareness of the language of assessment and provided guidance on generating assessment items with construct validity that was visible to teachers and learners.

Hughes and her colleagues adapted the tool for use across subjects, and developed the CRAS (Complexity, Resources, Abstractness and Strategy) scale (Figure 4-12).

The CRAS scale of demand involved three changes to the Edwards & Dall'Alba scale

- The two dimensions, *openness* and *implicitness* were merged into a new dimension called *resources*, as both of the dimensions are about students use of resources whether those resources are given (the data referred to in implicitness) or internal (the knowledge and ideas referred to in openness). The new dimension relates to the information given and how much candidates have to generate their own information, as well as what they do with that information.
- A dimension called *strategy* was added. The original scale did not include a dimension relating to students devising and maintaining a strategy for answering the question and for communicating an answer. Cognitive strategy is used to signify the extent to which students use operations and procedures to select relevant information, select appropriate strategies for tackling the task and monitor and regulate their cognitive processes.
- Six defined levels for each dimension was changed to a 1-5 continuum with only levels 2 and 4 described verbally. The language used in the Edwards scale was science specific; having less strictly defined dimensions makes it easier to apply to other subjects. Also the continuum from 1-5 with only three levels defined allows examiners to use their professional judgement in applying the scale.

The developers argued the existence of this type of scale on the grounds of validity. As teachers and learners' expectations are created by previous exam questions, and marking schemes as well as specifications; this scale was used as a communication tool rather than a development tool. An assessment item was given a number based on each of the categories.

4.4.3 Webb's depth of knowledge

A similar tool developed for analysing cognitive demand is Webb's depth of knowledge (DOK) scale (Figure 4-13) (Webb, 1997).

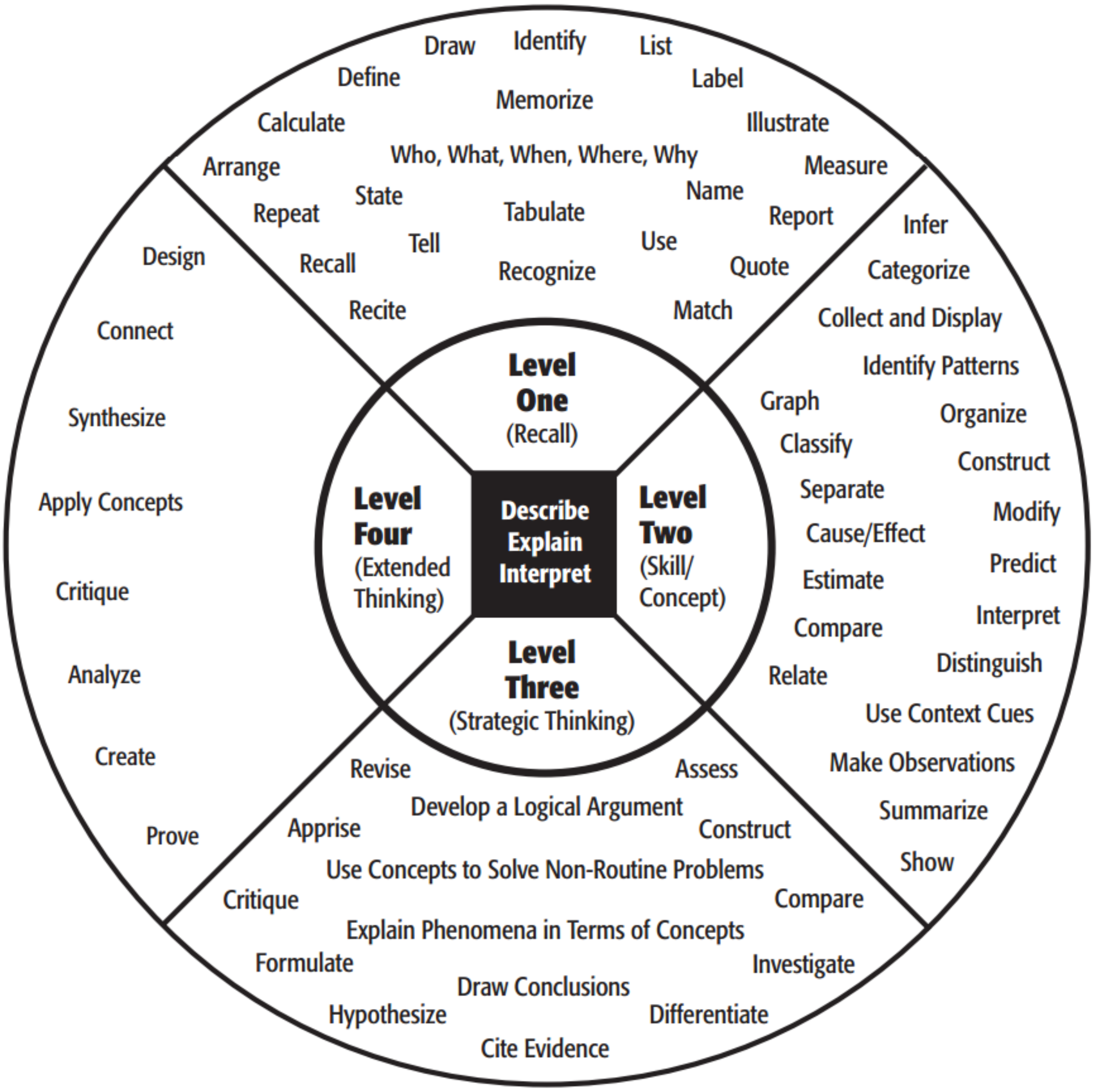


Figure 4-13 Depth of Knowledge as given by Webb (1997)

Level 1 Activities	Level 2 Activities	Level 3 Activities	Level 4 Activities
Recall elements and details of story structure, such as sequence of events, character, plot and setting. Conduct basic mathematical calculations. Label locations on a map. Represent in words or diagrams a scientific concept or relationship. Perform routine procedures like measuring length or using punctuation marks correctly. Describe the features of a place or people.	Identify and summarize the major events in a narrative. Use context cues to identify the meaning of unfamiliar words. Solve routine multiple-step problems. Describe the cause/effect of a particular event. Identify patterns in events or behaviour. Formulate a routine problem given data and conditions. Organize, represent and interpret data.	Support ideas with details and examples. Use voice appropriate to the purpose and audience. Identify research questions and design investigations for a scientific problem. Develop a scientific model for a complex situation. Determine the author's purpose and describe how it affects the interpretation of a reading selection. Apply a concept in other contexts	Conduct a project that requires specifying a problem, designing and conducting an experiment, analysing its data, and reporting results/solutions. Apply mathematical model to illuminate a problem or situation. Analyse and synthesize information from multiple sources. Describe and illustrate how common themes are found across texts from different cultures. Design a mathematical model to inform and solve a practical or abstract situation

Figure 4-14 Depth of Knowledge as given by Webb (1997) (continued)

The DOK model is used to analyse the cognitive demands of both assessment and curricular material. Curricular elements are categorised based upon the cognitive demands. Each grouping of tasks reflects a different level of cognitive expectation, or depth of knowledge, required to complete the task (Webb 1997) (Figure 4−14).

This framework offers a more holistic view of learning and assessment tasks and requires analysis of both the content and cognitive process demanded by any task. Webb's depth of knowledge (DOK) approach is a simpler but more operational version of the SOLO Taxonomy (Biggs & Collis, 1982) which describes a continuum of student understanding through five distinct stages of pre-structural, unistructural, multistructural, relational and extended abstract understanding.

4.4.4 PISA 2015 Framework

The PISA 2015 Framework uses an adapted version of Webb's Depth of Knowledge grid and includes a scale of knowledge and competencies (Figure 4-15).

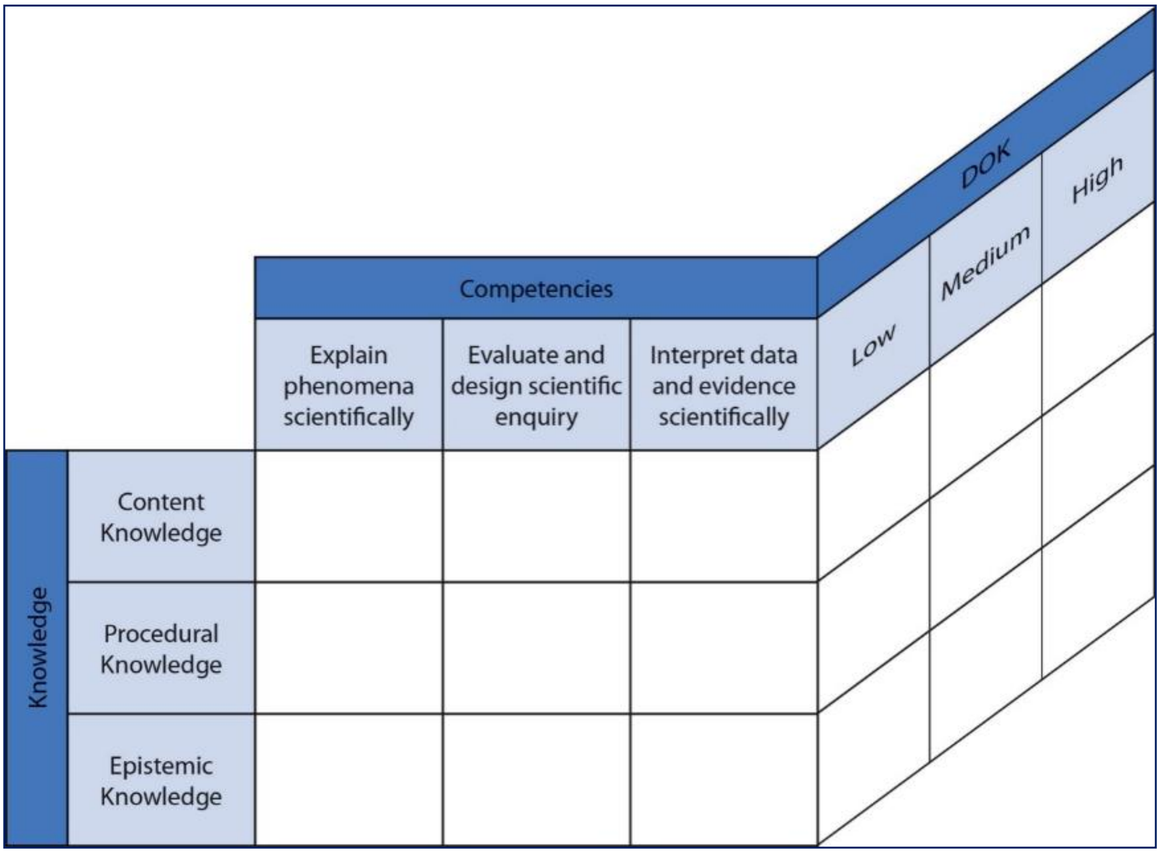


Figure 4-15 PISA 2015 Framework for Cognitive Demand

As the competencies are the central feature of the framework, the cognitive framework needs to assess and report on them across the student ability range. Webb's Depth of Knowledge Levels offer a taxonomy for cognitive demand that requires items to identify both the cognitive demand from the verbal cues that are used, e.g., analyse, arrange, compare, and the expectations of the depth of knowledge required. This results in a three dimensional framework for assessment items: knowledge dimension; depth of knowledge (DOK); and competencies[36].

The depth of knowledge dimension is categorised as low medium or high.

- **Low** - Items that require students to carry out a one-step procedure, for example recall of a fact, term, principle or concept or locating a single point of information from a graph or table.
- **Medium** - Items that require students to use and apply conceptual knowledge to describe or explain phenomena, select appropriate procedures involving two or more steps, organise/display data, interpret or use simple data sets or graphs.
- **High** - Items that require students to analyse complex information or data, synthesise or evaluate evidence, justify, reason given various sources, develop a plan or sequence of steps to approach a problem (OECD, 2013).

4.5 An assessment framework for Ireland

Although each of the scales described in the preceding section could have been used for assessment items in Ireland, it was decided to design a framework which included scales of cognitive demand, knowledge dimensions and assessment criteria. The Edwards scale was developed to allow teachers to analyse the cognitive demand of the learning objective, made by the learning task, and evaluated by the evaluation instrument, and in that way was designed to help teachers to develop learning activities and evaluation tasks. This is similar to the functions that a framework would serve in Ireland, but the elements used in the Edwards scale were different to the elements used in the framework for learning outcomes described in Chapter4. It was decided, that in as far as possible, the assessment framework should use the same language and the same metrics as the learning outcomes framework. Teachers are familiar with Bloom's levels of cognitive demand, as this concept is used extensively in in-service programmes. The Edwards scale

[36] The PISA competencies align more closely with the Irish science assessment criteria rather than the key skills.

is ultimately a one-dimensional scale of cognitive demand in different areas, i.e. complexity, openness, implicitness and abstractness. It was thought important that the knowledge dimension was included. Teachers will have to interpret learning as process rather than as product, so for that reason the knowledge dimension is an essential component. This will help teachers become familiar with different types of knowledge, particular with the complex concept of metacognitive knowledge.

The complexity scale on the CRAS scale is broadly mirrored by the cognitive scale on the learning outcomes scale. However, The CRAS scale was designed for assessment specialists, to enable them to develop a common language of assessment, rather than to make the learning in assessment visible. It is focused on categorising assessment for evaluation as it was designed to measure comparability between assessment items rather than as a tool to provide rich information about learning that is being measured. The strategy scale from the CRAS scale would add to the information from the learning outcomes framework; however, it was felt that it added an unnecessary layer of complexity that was not justified by the extra information that it would provide. The use of a sliding scale was also considered, as many questions will fall between the scales. Whole number scales were preferred to sliding scales. The position on the scale will still be down to professional judgement of practitioners, and will depend on the context of the task as well as the command term.

Of the three frameworks, PISA is most similar to the Irish framework, and it informed the Irish framework. PISA assessment is mapped onto a three dimensional framework; Depth of Knowledge (DOK) competencies, and knowledge. Figure 4-16 shows a sample PISA 2015 assessment item, Figure 4-17 indicates the levels allocated to it from the PISA framework.

The Depth of Knowledge, is replaced in the Irish framework by knowledge dimension, for the reasons mentioned above; this was considered necessary to support teachers in interpreting learning outcomes. The PISA competencies - content knowledge, procedural knowledge and epistemic knowledge in some way equate to the Irish assessment criteria of content knowledge, application, analysis and evaluation. Rather than using the PISA scale of depth of knowledge, which is scored as high, medium or low, the Irish framework uses Bloom's taxonomy, as it provides richer information, and when aligned with the knowledge dimension gives a very clear picture of the type of learning involved. Therefore the framework has a knowledge dimension, a cognitive process dimension (based on Bloom's taxonomy) and an assessment criteria dimension. Applying this framework to the PISA item would give a diagram such as Figure 4-18.

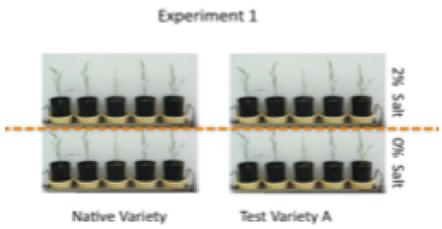
Experiment 1

Experiment Location: Inside a local greenhouse

Hypothesis: Test varieties of rice plants will yield more rice grains in salty soils than native rice plant varieties.

Experiment Description:
Two varieties of rice seedling plants were grown; one variety native to the area, and one test variety. Ten seedlings of each variety were grown, each in a separate pot. The plants were watered twice a week and given 10 hours of sunlight a day.

There were two types of watering treatments. Five plants of each variety were watered with 0% salt solution, and plants watered with 2% salt solution. On the first day of the first week, 500 mL of salt solution was poured onto the base of each plant. Plant height was measured each week.



Experiment Length: 8 weeks

Item 1

Which of the following research questions does Experiment 1 investigate?

(A) How does the amount of sunlight affect the growth of the rice plants?
(B) How does the concentration of salt affect the growth of rice plants?
(C) How does the amount of water affect the growth of the rice plants?
(D) How many rice plants can grow in a pot of soil?

Scoring 1

Question Intent

Context: *Personal | Environmental Quality*
Competency: *Evaluate and design scientific enquiry*
Knowledge: *Procedural*
System: *Living*
Depth of Knowledge: *Medium*

Full Credit

Code 1: *B*

No Credit

Code 0: *Other responses.*
Code 9: *No response.*

.

Figure 4-16 Assessment Item from PISA 2015

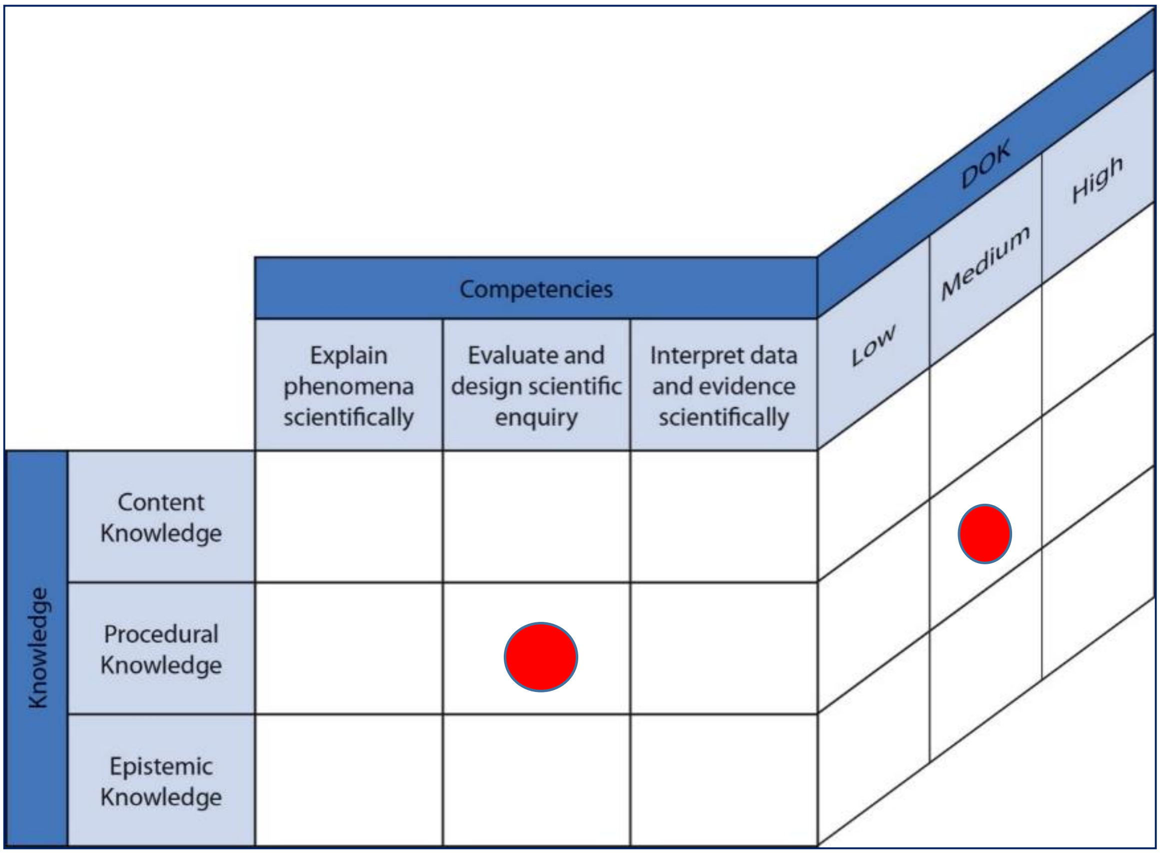


Figure 4-17 PISA assessment item allocated a scale on the PISA framework

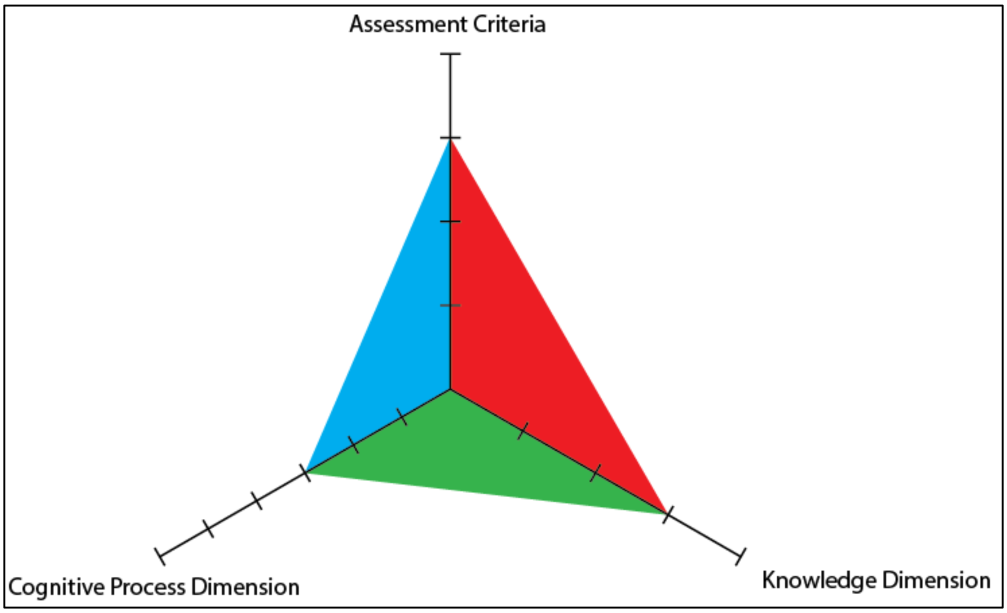


Figure 4-18 PISA assessment item allocated a scale on the three axis scale

The organising framework for the learning outcomes is three-dimensional; knowledge, cognitive process and key skills. The assessment framework is also three dimensional, with key skills are replaced by assessment criteria. The key skills are embedded in learning outcomes, and are developed as students engage in the learning that leads to a particular outcome. Assessment measures a student's achievement of outcomes based on their ability to perform tasks. The assessment criteria are performance descriptors, and so it is appropriate to include them in the assessment framework. The framework was renamed as the *3-axis scale of assessment item demand.*

Now any assessment task can be plotted or considered based on three criteria. In the next section, a number of sample assessment items are discussed using this 3-axis scale of demand framework.

4.6 Conclusion

Throughout this work there has been an emphasis on the need to align curriculum assessment and instruction, and an organising framework was developed to support that alignment. It informed the development process, in that it was possible to map the range of outcomes of differing levels from each domain and furthermore, show that within each unit there was an appropriate balance of different types and levels of outcomes, and secondly it provided a framework on which to construct outcomes that would indicate the level of demand/complexity intended by the curriculum developers. Given the broad nature of the learning outcomes, there is an expectation for teachers to use their professional judgement and choice in planning for teaching. An organising framework may help them to choose appropriate learning teaching, and assessment approaches, with a knowledge of the skills that students should be developing, and the level of cognitive demand that their knowledge entails. Students may use the organising framework to provide them with an insight into the nature of the learning experience ahead of them and also what will be expected of them in terms of assessment. Teachers may use the organising framework to achieve assessment alignment. This will be discussed further in Chapter 5.

There are some caveats about the organising framework. It assumes that the curriculum is a rational linear planning process, which of course it is not. Critics will argue that assigning numbers to learning outcomes is a paper exercise that relays little information, as the context in which the outcomes are achieved is the key determinant on the skills and knowledge that are developed by the learner.

The framework is based on the assumption that all learning outcomes are capable of being specified in advance, and that success depends on a set of predictable outcomes that are the same for all learners being achieved. The framework would be counter-productive if using it restricted spontaneity and flexibility. It is the teachers' role to achieve a balance between over-planning and lack of organisation. The framework may be useful as a retrospective tool to critically examine a lesson, a task or a unit of instruction. It is also important to note that planning can provide direction without overbearing control. Planning may bring coherence to teaching and learning, but should not control it.

5 Measuring outcomes of learning

This chapter gives an overview of current thinking about assessment and the role that it plays in teaching and learning. It discusses the current Leaving Certificate examination, and suggests ways in which the high-stakes nature of the examination can drive meaningful learning if the assessment is constructed using the organising Framework for Assessment based on a taxonomy of learning, discussed in section 4.4

5.1 Assessment and its purpose

Assessment is the practice of collecting evidence of student learning. It is a critical and integral part of classroom instruction, and serves several purposes for different stakeholders. First and foremost, it gives feedback to students, teachers, schools and parents on the effectiveness of teaching and on students' strengths and weaknesses in learning. Second, it provides information to schools, school systems, government, third level and further education institutions and employers.

Assessment approaches, the kinds of assessment tasks and questions, and the reporting methods send powerful messages to students not only about their own learning, but also about the nature of learning itself. Assessment is a powerful tool; it strongly influences the way students think about themselves, and shapes parent and community beliefs about learning – sometimes in unintended ways (Masters 2013)

The reasons for carrying out educational assessments can be grouped under three broad headings:

- Formative assessment supporting learning
- Summative assessment for certification
- Evaluative assessment for accountability

The most important role of assessment is in promoting learning and monitoring students' progress. However, at upper second level education, the high stakes nature of assessment for certification and selection tend to dominate.

Dylan Wiliam argues that policies of educational assessments can sometimes get it wrong, particularly when assessment that is used to measure attainment (summative assessment) is used for accountability (evaluative assessment) (Wiliam 2000). If this happens, there is a danger that assessment may become uncoupled from learning, and the huge contribution that assessment can make to learning is lost. He argues that furthermore as a result of this separation, formal assessment tends to focus just on the outcomes of learning. This leads to predictability, which allows teachers and learners to focus on only what is assessed, and the high stakes attached to the results create an incentive to do so

This creates a vicious spiral in which only those aspects of learning that are easily measured are regarded as important, and even these narrow outcomes are not achieved as easily as they could be, or by as many learners, were assessment regarded as an integral part of teaching (Wiliam, 2000).

A recent report for the National Foundation for Educational Research *Where have all the levels gone?* (Brill et al. 2013) highlighted the role of teachers' professional development in changing the relationship between teaching and learning. The report says that a *shared understanding of assessment is inextricably linked with teachers' professional development* and that a culture and discourse of high-quality assessment throughout teachers' careers will lead to assessment being used as a tool to promote learning rather than a tool to find out what a student knows, or don't knows (Brill& Twist 2013). Changing mind-sets and developing assessment and reporting tools to support such change are key to educational research goals. Masters (2013) suggests that the kind of change in mind-set required to bring about sustainable change in educational assessment may require a transition phase, in which processes based on differing mind-sets operate in tandem. Such a transition phase was used in the implementation of project maths in Ireland. The implementation on a phased basis was to facilitate as much engagement with practitioners as possible so that capacity would be built gradually and the initial group of teachers could bring the experience of the classroom to the curriculum developers and make the change sustainable. 24 schools implemented an innovative mathematics specification on a phased basis over 6 years. Their experiences and reflections informed the development of the final specification for mathematics prior to a National implementation in 2013[37]. Project maths is still in its early days in terms of large scale curriculum change, but early indications are that the changes are happening in classrooms, and though teachers found it difficult, many of them report that they would not go back to the *old way* of teaching (Jeffes et al., 2012)

According to Stobart, determining the validity of national assessment is not a single judgement that is constant over time. It is a series of judgements related to the purposes for which assessment is used. Some purposes may be easier to validate than others (Stobart, 2009). The Leaving Certificate as an examination instrument has strengths in that the tests are rigorously constructed and administered with utmost integrity. However, as discussed in Chapter 2, there are concerns that the results are being used for too many purposes and that the high stakes accountability purposes are now distorting teaching and learning by encouraging narrow teaching to the test. Stobart argues that the validity of high stakes national assessment would be enhanced by a reduction in their accountability purposes. He suggests that a move to more *intelligent accountability* would introduce a wider range of indicators and place less emphasis on schools' test results. This may then allow more significance to be given to teachers' assessment, which in turn leads to improved construct validity.

Where summative becomes the hand-maiden of accountability matters can get even worse, for accountability is always in danger of ignoring its effects on learning and thereby of undermining the very aim of improving schooling that it claims to serve. Accountability can only avoid shooting itself in the foot if, in the priorities of assessment design, it comes after learning (Black, 2014)

When assessment is focussed on learning rather than on reporting, the level of demand, and the range of learning that is assessed require careful consideration, and also the assessment needs to be planned in conjunction with the teaching and learning. To support learning, assessment must measure the learning that is desirable i.e. the learning intention rather than the learning outcome. In a report on *International Comparisons in*

[37] http://ncca.ie/en/Curriculum_and_Assessment/Post-Primary_Education/Project_Maths/

Senior Secondary Assessment the Office of Qualifications and Examinations Regulation (OFQUAL) commented that demand is a challenging concept, and that it is important to distinguish *cognitive demand* from *difficulty*. Difficulty refers to success rate for a particular question. If a large proportion of students do not perform well on a task or question, it is considered *difficult*. In contrast, demand relies on the *judgement of experienced professionals as to the challenge that a question should pose, based on the various cognitive processes and knowledge that it requires* (Ofqual, 2012).

Ahmed & Pollitt (1999) define assessment demand as *the level of knowledge, skills and competence required by the typical learner*

They argued that demand within a qualification or assessment is related to;

i) the amount and type of subject knowledge required to be assimilated;

ii) the complexity or number of cognitive processes required of the student, the extent to which the student has to generate responses to questions from their own knowledge, or the extent to which the resources are provided;

iii) the level of abstract thinking involved;

iv) the extent to which the student must devise a strategy for responding to the questions (Ahmed et al. 1999).

Science is a practical subject, and assessment of practical work that is reliable and valid has been the subject of extensive research. Recent research in the area of practical work (Abrahams & Millar 2008)(Reiss & Sharpe, 2012) describe the significant influence of the curriculum and, in particular, its associated impact on the practical work that teachers opt to do. It has long been recognised (Donnelly *et al.,* 1996; Pollard *et al.*, 2000) that, to a very considerable extent, it is assessment that drives what is taught, to the extent that teachers' preferences for using different types of practical work are routinely influenced by their considerations of curriculum targets and methods of assessment (Abrahams & Saglam 2010).

In order for assessment to be effective, it is necessary to know what it is that is being assessed, be that conceptual understanding, procedural understanding, process skills or practical skills. In order to assess these areas, it is necessary to understand the meanings of these terms.

By conceptual understanding we mean a knowledge base of substantive concepts such as the laws of motion, solubility or respiration which are underpinned by scientific facts. By procedural understanding we mean *the thinking behind the doing* of science and include concepts such as deciding how many measurements to take, over what range and with what sample, how to interpret the pattern in the resulting data and how to evaluate the whole task. (Gott et al., 2002)

Assessment and Inquiry-Based Science Education: Issues policy and practice (Harlen, 2013) brought together the thinking on assessment of inquiry-based science from an international conference *Developing Inquiry-based science education: New issues,* of which assessment was a major theme. There was consensus at the conference that what is assessed influences the priority given by teachers to various learning outcomes and goals of learning, and for that reason it is critical that all of the important goals of education are included. Some of the greatest challenges were perceived by the conference participants are in relation to involving teachers in assessment. Teachers require help to develop assessment literacy.

It is interesting to see what happened in New Zealand when two significant systemic policy changes on assessment of practical work impacted on teachers practice. The first was a new curriculum that required the teaching of science investigation and the second, internal assessment of science investigation for National Certificate of Educational Assessment (NCEA). Research carried out to ascertain the effect of those assessment changes on teachers practice are interesting (Moeed, 2011). The findings suggest that teachers changed their practice of teaching science investigation in response to the change in policy of assessment. The consequence of this change led to students being trained to (mostly) *learning* a fair testing type of investigation to gain NCEA credits and grades, at the cost of students learning that science is predicated upon investigation.

This paper argues that Year 11 science teachers reconciled the tension between the curriculum requirement of an open-ended investigation and the assessment of a fair testing type of investigation by teaching mainly what would be assessed for NCEA credits and grades.

The implication of the findings of the research was that in response to the assessment, teaching of investigation was narrowed to a fair testing approach. Many assessment strategies can focus on what is relatively easy to measure, as outcomes become broader and higher order, assessing them reliably and validly becomes much more problematic. School-based assessment, where teachers use their professional choice in designing assessments that best suit the student, the learning situation and the skill focus, is arguably the best way to assess student capacities in relation to higher order outcomes (Black et al., 2003). Such tailored assessment provides rich information on both learning and progression. Although the marks that students receive in school-based assessment will not directly contribute to the students Leaving Certificate grade, the structure and nature of the summative examination at the end of the course can potentially have a profound effect on the formative assessment that a student receives throughout the course. The external high-stakes Leaving Certificate examination exerts a very strong influence on teaching and learning, and it is argued that it could be used in a positive way, not just as a tool for determining achievement, but as one for setting promoting the kind of teaching and learning that is considered desirable.

The effect of high stakes National Assessment internationally was reviewed by the *Assessment of Teaching and learning of 21st Century Skills*[38] project (ACT21S). The project summarised case studies from countries around the world where state accountability assessment was used, either as an exit examination or as a higher level education admission. The countries included more than a dozen states in the US, England, Australia, countries in Eastern and Central Europe, China, Hong Kong, Israel, Japan, New Zealand and Shri Lanka. In summary they document that in those countries:

- Assessments signal priorities for curriculum and instruction; high visibility tests serve to focus the content of instruction.

[38] http://www.atc21s.org/

- Teachers tend to model the pedagogical approach reflected on high-visibility tests.
- Curriculum developers, particularly commercial interests, respond to important tests by modifying existing textbooks and other instructional materials (Binkley et al. 2012)

These effects clearly impact on the educational experience of learners, highlighting the importance of the alignment of the assessment with the intended learning intentions of the curriculum.

Traditionally in Ireland the syllabus was the final dictate for the state examination. If it wasn't written in the syllabus document, it couldn't be asked in the Leaving Certificate examination. Flexibility and the use of tailored contexts adds authenticity to the learning, and to the assessment, and obviously it is impossible to list all the possible contexts or applications that can be asked and it is also impossible to list them all in a specification document. However, that is not to say that there should not be shared interpretations of the types of tasks that students should be able to do and the standard at which they should be able to do them. Shared interpretations of learning outcomes cannot and indeed should not be possible by a specification document alone. Assessment is a very important contributor to the shared understanding of what students are expected to do at the end of a period of study. What is changing quite dramatically is the role of assessment and evaluation and the important question of not only how we should measure outcomes, but also what outcomes should be measured.

This has implications for how we engage learners and particularly for how we assess learning, and the learning we assess - whether it be for formative, summative or for selection purposes. In a presentation to the Transition Conference in Dublin in June 2013 supporting *a better transition from second level to higher education*[39] Dr Anne Looney, Chief Executive officer for the NCCA noted the impact in Irish education of *Goodhart's law*. Goodhart's law was first developed to describe the effect of regulation on investment behaviour. The law has now come to be applied to social processes such as educational

[39] Available at http://www.transition.ie/conference.html

assessment. Simply put, the law states that when any measure becomes a target it ceases to be an effective measure. She went on to talk about the increasing impact of transparency and on giving learners as much information as possible about the assessment processes and particularly where selection is at stake (Looney, 2013).

Investigations on the impact of different modes and methods of assessment on achievement and progress in post-secondary education have shown that clarity and transparency in assessment procedures, processes and criteria has underpinned widespread use of coaching, practice and provision of feedback to boost achievement, and that the high level of transparency encourages instrumentalism (Torrance, 2007). High stakes assessment has the potential to completely dominate the learning experience and *criteria compliance* replacing *learning*. With increasing transparency and the impact of Goodhart's law in an attempt to improve the quality of assessment, there is a danger of undermining the validity of the assessment experience.

5.2 Assessment in Practice

In 2013, the OECD compared the experiences of 28 countries and analysed the strengths and weaknesses of different approaches to assessment (OECD, 2013). At a time when education systems are placing much more importance on measuring student outcomes, international benchmarking and performance testing is becoming an increasing feature of education systems, and a driver of policy. The OECD report showed that the impact of Goodhart's law and the impact of transparency on examinations was a feature across school examination systems; it is not just an Irish problem. The OECD concluded that challenging those issues and improving the quality of assessment, featured a range of actions, five of which are particularly relevant to this work, the others are directions for policy which, although important, do not fall under the scope of this research. The five activities are:

- **Fostering synergies within the evaluation and assessment framework**
  It is important to develop a framework document that conceptualises the complete assessment framework and articulates ways to achieve its different

components. Part of the framework should be descriptions of how the assessment and evaluation can produce results that are useful for classroom practice.

- **Aligning learning goals with evaluation and assessment**
  Whereas it is possible to reflect broad educational goals in the curriculum, it is far more challenging to reflect them in assessment, particularly when assessment is used for purposes other than education such as accountability or selection.
- **Focussing on improvement of classroom practices and building on teacher professionalism**
  If the purpose of evaluation and assessment is to improve student learning then all types of assessment should have educational purposes. For this to happen, all those involved, from the teacher to the policy makes, need to have a broad vision of assessment and how it supports learning, whether summative or formative.
- **Effectively conceiving the accountability uses of evaluation and assessment results**
  Although evaluation and assessment provide a basis for monitoring and evaluating schools and systems, it has the danger of distorting the education process by narrowing the curriculum to only what is examined. An additional danger is that developmental function of evaluation might be limited. As a result, it is important to design assessment so that the undesired effects are minimised
- **Placing the student at the centre**
  Ensure that the assessment and evaluation processes focus on students' authentic learning, including evaluation of their own learning. The OECD report stresses that this should *extend beyond knowledge skills in key subject areas and include broader learning outcomes including students' critical thinking skills social competencies, engagement with learning and overall well-being*. (OECD, 2013).

In his book *Educative Assessment: Designing Assessments to Inform and Improve Student Performance* Grant Wiggins makes a case for assessment that should aim mainly to improve rather than to audit student performance (Wiggins 1998).

Wiggins suggests that well stated learning outcomes (and assessment specifications) should include three components:

- A doing component (what activity or process is involved?)
- A knowledge component (what is the intellectual content?)
- The criteria for satisfactory performance (what distinguishes those who have achieved the learning outcome from those who have not?)

The influence of cognitive psychology on learning has led to advances in our understanding of human learning and how students learn, and predicates for a new look at how learning is assessed and monitored. Rather that assess a snapshot of students' knowledge at a moment in time, more emphasis should be placed on finding out where students are in their learning and development their understanding (Masters, 2011). The only way we have of knowing this is by having a clear understanding how the learning is constructed, i.e. the skills knowledge and understanding that are intrinsic to a task or an assessment item. *Assessment as a discovery of where students are in their learning* (Masters, 2013) requires much more than familiarity with the intended curriculum; it depends on expert understanding of how learning occurs in a domain – a reference map that is built from research and knowledge about learning itself. As much importance should be put on the construction of knowledge as the knowledge itself.

An argument that is often used against moving towards skills based curricula, particularly in a high stakes situation such as the Leaving Certificate is that knowledge is somehow devalued, and that the balance between *hard knowledge* and *soft skills* is difficult to achieve. I would argue that the balance is achievable once there is a clear definition of the type and nature of the knowledge, and of the evidence required to demonstrate achievement of a learning outcome. Knowledge is always a desirable outcome of education. In order to be able to understand, adapt, apply, analyse, synthesise, and evaluate information, learners need to have access to that information in the first place. Unless the information is available from another source at the time it is needed, students have to recall it in order to use it. In such circumstances, the capacity to recall relevant knowledge is a prerequisite to displaying other higher order thinking skills. Even with information being so readily available from external sources, students need to have a solid body of fundamental knowledge. Learning information, by whatever means, is still a necessary part of learning in general. Learning for understanding is being able to use that knowledge in a meaningful way.

Teachers' willingness to embrace new assessment strategies, and their belief in a broad vision of assessment, and an understanding of its purpose, is critical for successful implementation. This broad vision and understanding that the value of assessment lies in its value for learning should be transmitted beyond the classroom, to school leaders, to parents and the wider public. As stated earlier, the alignment of assessment with broad educational goals is very difficult, and not always possible, but the key person to direct that alignment is the teacher. The professionalism of the teacher will be drawn on to ensure that authentic assessment is geared towards improving learning in the context of the broad educational goals. This is particularly difficult in the high stakes setting of the Leaving Certificate, where assessment for accountability dominates over assessment for learning.

The Analysis and Review of Innovations in Assessment (ARIA)[40] by the Nuffield foundation in the UK brought together information from initiatives and developments in assessment in England, Wales, Scotland and Northern Ireland. They focused on the role of teachers in formative and summative assessment in schools, and how innovative changes to assessment practice may be brought about most effectively. The report points out that there is '*a persuasive rationale for change but the fact remains that changes in assessment practice have been notoriously difficult to sustain'*. The report, Changing Assessment Practice: Processes, Principles and Standards (Gardner, Harlen, Hayward, & Stobart, 2008) goes on to say that changes in assessment usually arise out of innovation practices which require teachers to change some aspect of their teaching. Unless teachers have an in-depth understanding of the nature of the innovation and a belief in the rationale behind the change, innovative practice may end up being no more than a new way of carrying out established activities. Innovations in teaching, learning or assessment usually require a considerable extra workload to sustain them and often failed because of what is seen as a

[40] http://www.nuffieldfoundation.org/analysis-and-review-innovations-assessment-aria

top down directives designed to promote a change in teaching and learning rather than a measure designed to improve students' educational experience. Part of the *warrant* for change as the report puts it, is to provide clear evidence based reasons for change, so that teachers believe that change is necessary and in the best interest of students.

Too much testing has been blamed for narrowing the curriculum (Silva 2009), however in the Irish context it can be argued that too narrow curricula have constrained the testing. In her book *Next Generation Assessment: moving beyond the bubble test to support 21st century learning* Darling-Hammond (2014) describes assessment strategies along a continuum (Figure 5−1).

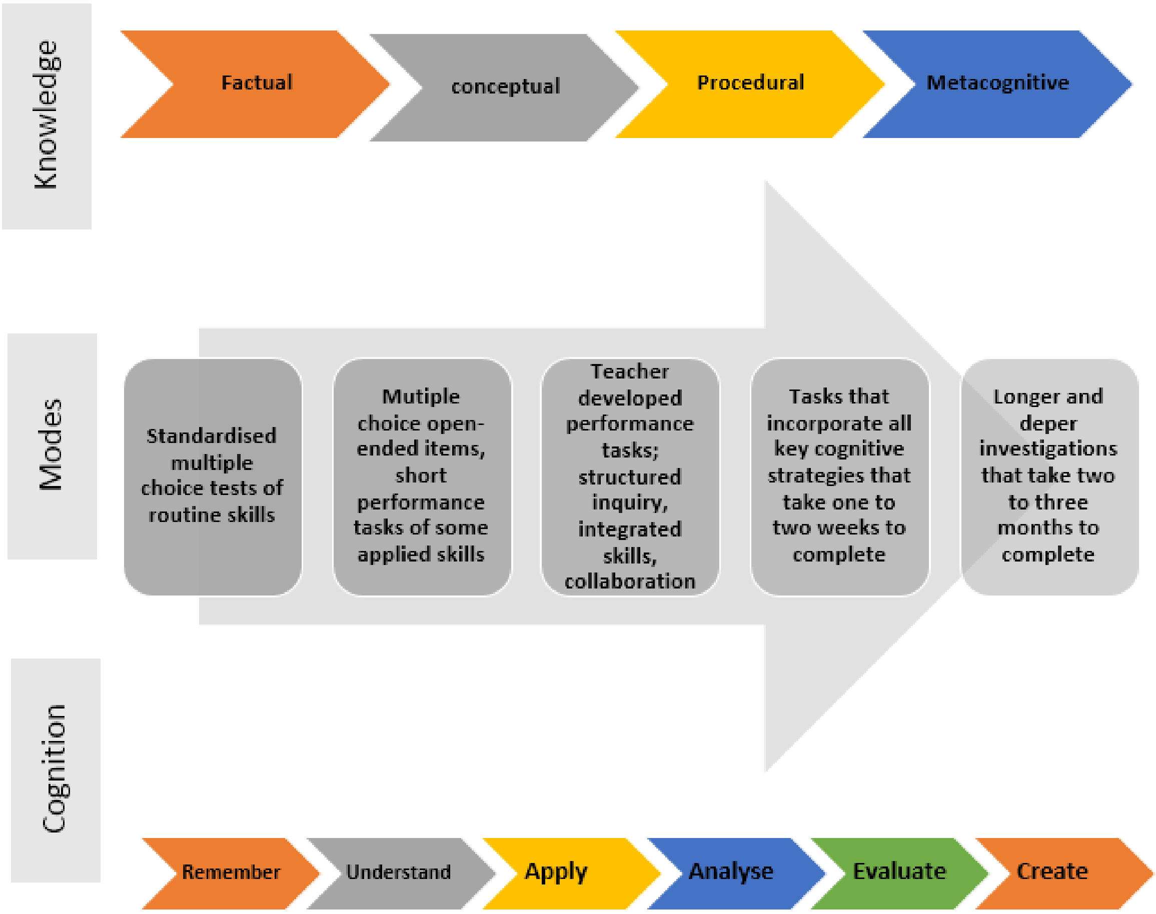


Figure 5-1 Assessment Continuum adapted from Darling-Hammond (2014)

Along the continuum at one end there are close-end items found in traditional tests. These items measure recall and recognition, but cannot measure higher level thinking skills or students ability to apply them. At the other end are assessments which require significant input by students in terms of independent thinking, strategising and application of understanding.

There is little dispute that assessment is an essential part of teaching and learning , (Brill & Twist, 2013), however, its role in curriculum planning is increasingly being seen as just as important. As well as being an important diagnostic tool, assessment can operationalise learning outcomes (Robin Millar, 2012). Successful learning outcomes require the integration of content and meaningful assessment with effective pedagogy, and that must be communicated very clearly to teachers, learners and their parents. Clearly aligned assessment shows how inquiry, innovative problem solving, and critical thinking can be used in the context of fundamental discipline knowledge. The more open-ended a learning outcome is, the more critical it is to establish what evidence is required to show that a learner has achieved it. Command terms used within an organising framework can provide a common language to describe not only what students should know and be able to do, but also at what level they should operate. When outcomes are built on a framework, decoding them through assessment built on a similar framework provides a road-map for teaching and learning.

Curriculum	Coherence	Pedagogy
drives instruction in ways that mimic not only the content but also the format and cognitive demands of tests	enables tighter control of teaching for purposes of curricular coherence	encourages use of information about student learning to guide ongoing teaching decisions
focuses teachers on useful content and supports more purposeful teaching	provides greater standardisation of what is taught across classrooms, and teacher accountability for covering expected content	makes assessment an integral part of the planning and teaching process, so that teaching can take into account what students know, believe, and bring to the classroom, as well as what they need to learn

Figure 5-2 Rationale for using assessment to direct teaching

Assessment can help to direct teaching and learning, by encouraging curriculum coherence through appropriate pedagogy (Figure 5-2) (Darling-Hammond, 2002).

5.3 Assessment in Ireland

5.3.1 Background

There are interesting lessons to be learned from past experience in Ireland. The introduction of the 2003 junior science syllabus heralded an innovative approach to science curriculum and assessment in Ireland. For the first time ever in Ireland, practical work was included in the assessment; this was done in an effort to change pedagogy towards inquiry-based learning. The view of the curriculum developers was that changing assessment would automatically change practice, increase student participation in practical science, and result in inquiry based science education. While there is evidence that practice changed, in that teachers included more practical work in their lessons (Eivers et al. 2008) there was less evidence of a wholesale change in pedagogy towards inquiry based learning.

In 2006 the DES commissioned the Education Research Council to survey science teachers in schools that had participated in the 2006 round of PISA. The survey examined teachers' views on the revised Junior Certificate Science Syllabus (rJCSS), and the linkages between the PISA science framework and science teaching in Irish schools.

Teachers were asked (through surveys and interviews) how their students' experiences in science classes had changed as a result of the revised syllabus (Table 5−1).The data supports the notion that as a result of the implementation of the rJCSS, students are spending much more time engaging in practical work, using investigative methodologies and participating in collaborative work; 43 % of teachers reporting that students had had either major increases or some increase in interest in learning science.

Although 87% of teachers indicated that they used an investigative approach to science learning, the report stated that a majority of teachers indicated that in over half of their lessons, students still performed experiments by following instructions, and 24% indicated that at least half of their lessons involved the teacher conducting experiments as a demonstration (Eivers et al. 2006). Almost half of the teachers surveyed reported that students never designed an experiment to answer a scientific question. It is clear that teachers have moved a good deal towards investigation and inquiry, however, there is still a reliance on the tried and tested ways of traditional experimentation. This may be tied in with the fact that many of the teachers interviewed expressed dissatisfaction with the assessment model. Some complained that there were too many mandatory activities in coursework A[41] with too much time being spent writing up experiments, with little attention to how well students actually carried them out. There is anecdotal evidence of students spending considerable time copying out *perfect* reports on experiments at the expense of actually doing investigations. Although the introduction of practical assessment was intended to reduce the focus on the written examination and to encourage an inquiry-based learning approach to Junior Certificate Science, however, most teachers reported no change in the emphasis they placed on preparing students for the written Junior Certificate examination.

This data is supported by a composite report on Science by the Inspectorate (Eemer Eivers et al., 2008). In it, the authors report many positive developments in science teaching following the implementation of the revised curriculum; however, they found that although practical laboratory activities were effectively organised in most schools, in some schools, students were not learning about science in an investigative way, as required by the syllabus. The chief examiners report for junior certificate science also affirmed the potential misalignment of the implemented and the intended curriculum (SEC 2010). It reported that there is evidence from the practical assessment that students are engaging in practical work during the year and are learning from the experience.

[41]There are two coursework elements in the Junior Certificate examination. Coursework A is a record of mandatory experiments completed during the course of the three years. Coursework B is an investigation carried out under the supervision of the teacher, marked by an external examiner.

	N	Major increase	Some increase	No change	Some decrease	Major decrease
Involvement in practical work	433	42.7%	43.3%	13.3%	0.5%	0.0%
Use of investigative approach	429	24.3%	62.7%	13%	0.0%	0.0%
Participation in collaborative group work / discussion	431	9.8%	58.3%	29.6%	1.8%	0.7%
Interest in learning science	433	5.3%	38.0%	53.3%	3.0%	0.5%
Relevance of content to everyday lives	429	5.3%	55.4%	35.9%	3.2%	0.1%
Ability to apply science processes	431	4.3%	47.3%	42.7%	4.8%	0.9%
Use of ICTs in science lessons	430	3.0%	24.8%	69.8%	1.9%	0.5%
Understanding of science concepts	431	2.8%	38.1%	50.5%	7.8%	0.8%

Table 5-1 Percentages of teachers indicating the extent to which the rJCSS resulted in changes in Third Year students' experiences of science lessons (Eivers et al. 2006)

However, it also reports that while presentation of procedures and recording of data was *excellent*, identification of controls and variables was *good*, conclusions, analysis and comments were *sometimes less than what was required*. As part of the examination process, students carry out coursework B which can be either an investigation of their own choice or two investigations set by the State Examinations Commission. A disappointing statistic is that although the option is there to design an investigation of their own choosing, 99% of students opt to do the set investigations.

5.3.2 Practical assessment in Ireland

There are concerns about whether the current practice of assessing practical skills by means of a written paper in the Leaving Certificate is a valid assessment of students' practical abilities, and about the effect that such an assessment has had on the experience of practical work gained by students. There was concern in Ireland that the limited nature of the assessment of practical science at Leaving Certificate was indirectly encouraging many teachers to reduce the time spent on practical work in favour of preparing for the written assessment. (Bennett & Kennedy 2001). The effect of assessment on teaching and learning is one of the driving reasons that Ireland has been trying to design valid and reliable ways to assess practical work in the LC sciences. Evidence following the introduction of practical assessment at junior cycle supports the long held view of curriculum development groups that assessment has the power to support good pedagogy, and with the right support provide a way of measure some of the knowledge and skills that cannot be validly assessed in the written paper alone.

Ireland is unusual internationally in that it does not assess science practical skills. Numerous reports and studies over the past thirty years have recommended practical examinations. In its report *Benchmarking School Science, Technology and Mathematics Education in Ireland against International Good Practice* (Walsh, 1999) The Irish Council for Science Technology and Innovation (ICSTI) pointed out that

> *Ireland, uniquely, does not provide for the assessment of practical work in most science subjects at post-primary level. This results in a significant lack of congruency between the aims and objectives of the relevant subject and its assessment.*

The ICSTI report also noted that *assessment is central to the enhancement of teaching and learning in all subjects* and recommended that *the practical dimension of science subjects be reflected in their assessment*. However, the fact that, in Ireland, assessment for the certificate examinations is wholly external adds particular complexity to the task of developing an appropriate model for assessing practical work.

The ESRI report *Who Chooses Science? Subject Take-up in Second-Level Schools* (Smyth & Hannan 2002) reported that student uptake of Leaving Certificate science subjects tended to be higher in schools that emphasised practical work and student participation in laboratory sessions. The report also recommended the introduction of a second, practically based component of assessment for all Leaving Certificate science subjects. The report of the Task Force on the Physical Sciences indicated that students enjoy practical work in science and stated that there was almost universal support for its inclusion as a component in the assessment of science (Millar & Murphy 2002).

In an effort to find a solution to the assessment of practical work, the DES established a steering group to carry out a feasibility study on practical assessment in LC physics and chemistry as far back as 1998. The main focus of the feasibility study was to design and trial a reliable and valid means of assessing practical work, and in doing do raise the profile of practical work in schools. The feasibility study proposed a model of individual assessment of each student by a visiting examiner.

Each examination lasted 15 minutes as shown in Table 5−2.

Phase	Assessment to be made	Time allocated	Maximum marks
1	Examination of practical notebook	5 minutes	21
2	Understanding of experimental procedure	5minutes	18
3	Assessing generic practical skills	5 minutes	21

Table 5-2 Outline of practical assessment model proposed by the 1998 feasibility study

The examiner was required to inspect every student's practical book to check that each of the reports on practical work that the student had carried out throughout the two years of LC contained an introduction, a procedure and a set of results. A single mark was awarded for every practical with the three features, up to a maximum of 21. If the examiner came across a report that did not have the three characteristics, he/she was instructed to ignore that practical and continue reviewing the reports until 21 marks had been awarded or no reports remained. Thus a student would only be given a mark less than 21 if the notebook contained less than 21 practical reports with the three characteristics. It should be noted that the quality, including accuracy and analysis of results, was not assessed.

Phase two of the examination was to examine student ability to explain the practical work which they had performed (Kennedy, 1997). Students were asked questions about the reports in their notebook and marks were awarded on a three-point scale (Table 5−3).

Student readily able to answer all questions	18 marks
Students able to answer most questions	12 marks
Students able to answer some questions, prompting required	6 marks

Table 5-3 Marking scheme for phase 2 of the 1998 feasibility study.

The questions were about how they carried out the mandatory experiments, what procedures they used, and how they ensured the safety of themselves and others. The questions were based on recall of the information in the laboratory notebook.

Phase three of the examination was assessment of generic practical skills. The examiner chose two experiments from the practical notebook. In one, students had to perform a procedure with apparatus already set up and in the second, the student had to set up the apparatus e.g. to titrate to an end point and set up a reflux apparatus in chemistry.

The report of the feasibility study gave rise to much discussion and debate about issues associated with validity and reliability of practical assessment. Matthews argued that the ability to use a particular piece of equipment, e.g. an electronic balance, out of context did not provide useful information about the students' practical skills in an authentic setting. He argued that the tasks as set out in the feasibility were trivial and not worthy of the time and money spent on a formalised system of assessment. He argues that breaking science activities into unconnected discrete activities misses the essential nature of practical science (Matthews & Mckenna 2005). What emerged out of the discussions was that in the context of Irish education, the detail of the knowledge and skill associated with practical work that are desirable to assess, and capable of being assessed rigorously, should be the subject of extensive research and trialling.

5.3.3 Is it the assessment or the assessment target that is the issue?

As discussed in Chapter 2, there has been criticism of the Leaving Certificate by teachers, parents, third level and industry as highlighted by the review of senior cycle the various ERSI reports. It might be expected that a simple answer to these criticisms would be to change the examination system completely and in doing so solve the problems of the skills deficit, the outmoded pedagogy, and the stress of young people all in one go. The reality is that there is a very high level of public confidence in the quality of the Leaving Certificate examinations and in the standards established and in the fairness with which those standards are applied. Results achieved in the state examinations are generally seen as sound predictors of performance in further study and in the world of work (NCCA/HEA, 2011). The State Examinations are highly transparent, and information regarding the setting and marking of examination scripts is easily accessible (SEC, 2012). Students, their teachers and their parents are familiar with how examination scripts are marked and they know what types of answers are likely to result in high grades. Although the assessment is the usual target of criticism of what is wrong with the system, the full extent of what can and should be assessed in any examination are set by the syllabus for that subject. All of the test items in any examination must be based on some aspect or aspects of the relevant syllabus, and the sampling of the syllabus that takes place in any year is a reasonable reflection of the relative importance of the various content areas and skills. Alignment with the syllabus is an essential element in protecting validity.

The SEC takes stringent steps to ensure the faithfulness of the examination to the syllabus. Drafters and setters who prepare the state examinations receive training from the SEC and are guided and bound by the instructions laid out in the SEC's *Manual for Drafters, Setters and Assistant Setters*. This requires that those working on the preparation of material for assessment ...select *a range of topics and questions which will satisfy the relevant syllabus aims and objectives, and be representative of the syllabus content, as defined in the published syllabus.*...(SEC, 2007). In the Manual for Drafters, Setters and Assistant Setters, the SEC sets out very clearly the key principles that underpin and inform the preparation of test items and ensure their reliability and validity. The preparation and completion of an assessment grid for each examination is an integral part of the drafting and setting process every year. The manual for drafters and setters provides a sample assessment grid. Figure 5−3. The assessment grid for each item identifies the content area and the assessment objective(s) being tested by each question in the examination. The assessment objectives are written in terms of skills and usually reflect a taxonomy of educational objectives, such as Bloom's Taxonomy. Each cell in the grid represents the testing of the specified objective in the context of the specified content area.

content area / Assessment objective															Total
Knowledge															
Comprehension															
Application															
Analysis															
Synthesis															
Evaluation															
Total															

Figure 5-3 Sample SEC assessment grid

This grid is adapted for each subject, for example, the assessment objectives for the Leaving Certificate physics syllabus are: knowledge, understanding, skills (practical) competence, and attitudes (Figure 5−4).

M36	**topic**	Knowledge	Understanding	Skills	Competence	Attitudes	Total
Motion	1. Linear motion*						
	2. Vectors and scalars						
Forces	1. Newton's laws of motion*						
	2. Conservation of momentum*						
	3. Circular motion						
	4. Gravity*						
	5. Density and Pressure*						
	6. Moments						
	7. Conditions for equilibrium*						
	8. Simple harmonic motion*						
Energy	1. Work						
	2. Energy						
	3. Power						

Figure 5-4 Physics assessment grid

Support for teachers and learners is also available in the form of explicit marking schemes and examiners' reports for the different subjects, which include an analysis of examination scripts. These are accessible on the SEC website[42]. When the examination results are issued in August every year, they are accompanied by a statistical analysis of student performance, including numbers taking each subject and the distribution of grades by subject and by gender. After the results are issued, any student who wishes may view his/her marked script or scripts. The examiners' reports on the various subjects include advice and recommendations to students and teachers about improving examination performance.

It is useful to consider an example of a particular examination question from a past LC examination paper. Figure 5−5 is a question from the 2011 Higher level LC biology examination assessing scientific process. This item requires recall of knowledge by students. Students learn the uses for various reagents and pieces of equipment, this information has to be recalled to answer the questions (a) and (b). During the course of their studies, students carry out prescribed practical experiments, variations on these set experiments cannot be assessed in the examination; students learn the procedure, results and conclusions of the experiments to recall in the exam, for example question (b) (iii) and (iv). Based on the Darling-Hammond continuum (Figure 5−1), this question is towards the left hand side of this continuum. In general, LC assessment in the science subjects tends towards the left hand side of this continuum for two main reasons. Firstly, the assessment is a once-off written test which severely restricts what is possible to assess, and secondly the level of specification of the syllabus content makes it difficult to assess higher level thinking skills and students' ability to apply them. The content, independent of how difficult it is, has all been seen before. It is very difficult to come up with multiple innovative ways of ask the same question when the minutiae of the content and the context are explicitly defined.

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[42] www.examinations.ie

Now consider an alternative question, shown in Figure 5−6, which is also on scientific process, but is based on the more open-ended learning outcomes from the revised specification in biology, in which the context for the investigation is not defined. Students are required to demonstrate greater depth of knowledge and comprehension that in the previous question. They are required to apply their knowledge to changing situations as they hypothesis, design, analyse, evaluate and justify previously unseen data and experimental results. The cognitive processes that are required by students in this question are as far as level 6, create. Although the level of demand is not excessive, the level of cognition is very high.

Investigation of the effect of ultra-violet light on bacterial growth is not listed in the specification, so it is a genuinely unknown, authentic context. Students cannot rely on recall; however, they will be able to use thinking strategies that they have developed through their learning – i.e. metacognitive knowledge, to propose a reasonable, testable hypothesis for the appearance of the white colony.

(a) State a use for each of the following in the biology laboratory:

(i) Buffer solution. ______________________________

(ii) Biuret test. ______________________________

(b) (i) In the course of your practical studies you used a solution of iodine in different investigations. State **two** different uses of the iodine solution.

Use 1. ______________________________

Use 2. ______________________________

(ii) State **two** different uses of a water bath in biological investigations.

Use 1. ______________________________

Use 2. ______________________________

(iii) In the course of your practical studies you found that heart rate and breathing rate increase with exercise.
Explain why this is the case.

____

____

____

(iv) In the course of your practical work you prepared a transverse section (T.S.) of a dicot stem for microscopic examination.
How did you prepare the T.S.?

____

____

Figure 5-5 Leaving Certificate Higher level Biology. 2011 Question 8.

Red bacteria from the same colony were spread on two sterile dishes with a sterile food supply. One dish was placed under an ultra violet light for several days; the other was placed in the dark. As a result, in both dishes new colonies appeared all of which were red except for one white colony in one dish.

i. State a hypothesis to suggest how the white colony could have arisen.

ii. describe how you could obtain some evidence to support your hypothesis

iii. In which of the dishes would you be most likely to have found the white colony? Give a reason for your answer.

Figure 5-6 Assessment of revised LC biology

In Section 5.2.it was suggested that well stated learning outcomes (and assessment specifications) should include three components:

- A doing component
- A knowledge component and
- The criteria for satisfactory performance.

Many learning outcomes in the revised science specifications include the first two components, the doing component is indicated by the action verb, which is backed up by a glossary linked to command terms, the knowledge component is provided by the rest of the learning outcome. The outcome does not indicate the criteria for satisfactory performance, although there are general assessment criteria indicating what high, moderate and low levels of achievement performance for both the written and the practical assessment look like. The learning outcomes are brief statements that are indicative of the type of activity or process involved and the type of knowledge required; in some cases, the content is specified. The learning outcomes cannot and should not be interpreted in isolation, they exist in relation to, and in the context of, all of the other learning outcomes in the specification.

This way of presenting the curriculum to teachers is very different to what they are used to, and has caused considerable anxiety about interpretation of learning outcomes. In previous syllabi, targets were very clearly defined in terms of content. It is understandable that teachers will wonder if they are covering the *right* content at the appropriate level and that students will be adequately prepared for the examination. It is important therefore, that the specifications are accompanied by detailed assessment materials that show examples of ways in which students have achieved particular learning outcomes. As was shown in Chapter 4, this is particularly true for the learning outcomes that are in the top half of Bloom's Taxonomy. The use of illustration for creating common understandings of learning outcomes is now a well-accepted form of curriculum support material in Ireland, but the nature of that material will have to be carefully considered. It will be most useful if it clearly demonstrates the kind of learner performance that is expected as well as the extent and level of discipline knowledge.

5.3.4 Setting Leaving Certificate within a Framework

In Ireland, all qualifications are mapped out onto the National Framework of Qualifications. The National Framework of Qualifications (NFQ) is a ten-level system (1–10) giving an academic or vocational value to qualifications obtained in Ireland. Each level is based on nationally agreed standards of what a learner is expected to know and be able to do after receiving an award made by a professional body.

The NFQ is linked to similar frameworks in Europe. There are two qualifications frameworks at European level:

1. The Framework for Qualifications of the European Higher Education Area also known as the *Bologna Framework*. This deals with higher education awards (NFQ 6-10)
2. The European Qualifications Framework (EQF), which deals with all NFQ levels including schools, Further Education and Training, and Higher Education

As well as the examinations being faithful to the syllabus, the Leaving Certificate examination is placed at a particular level on the National Qualifications Framework. The Ordinary level award is placed at level 4 and the Higher level is placed at level 5 (Figure 5−7).

Figure 5-7 National framework fan

The framework defines the levels in terms of three dimensions – *knowledge; know-how and skills*; and *competence*. The three dimensions are further subdivided. Table 5−4 outlines the definition of the dimensions for level 4 and level 5.

DIMENSION	Level 4	Level 5
Knowledge – breadth	Broad range of knowledge	Broad range of knowledge
Knowledge – kind	Mainly concrete in reference, and with some level of abstraction in theory	Some theoretical concepts and abstract thinking, with significant depth in some areas.
Know-how and skill – range	Moderate range of practical and cognitive skills and tools	Broad range of specialised cognitive skills and tools
Know- how and skill – selectivity	Select from a range of procedures and apply known solutions to a range of predictable problems	Evaluate and use information to plan and develop investigative strategies and to determine solutions to varied unfamiliar problems
Competence – context	Act in familiar and unfamiliar contexts	Act in a range of varied and specific contexts, taking responsibility for the nature and quality of outputs. Identify and apply skill and knowledge to a wide variety of contexts.
Competence – role	Act with considerable amount of responsibility and autonomy	Exercise some initiative and independence in carrying out defined activities, join and function within multiple heterogeneous groups.
Competence – learning to learn	Learn to take responsibility for own learning within a supervised environment	Learn to take responsibility for own learning within a managed environment
Competence – insight	Assume partial responsibility for consistency of self-understanding and behaviour	Assume full responsibility for consistency of self-understanding and behaviour

Table 5-4 NFQ Level indicators

In the LC, grades are awarded from A1 to F (Table 2−4). Recently, Aine Hyland, former professor of education in UCC presented a grid framework where she mapped the LC grades at Level 5 on the NFQ to a Revised Bloom's Taxonomy (Figure 5−8).

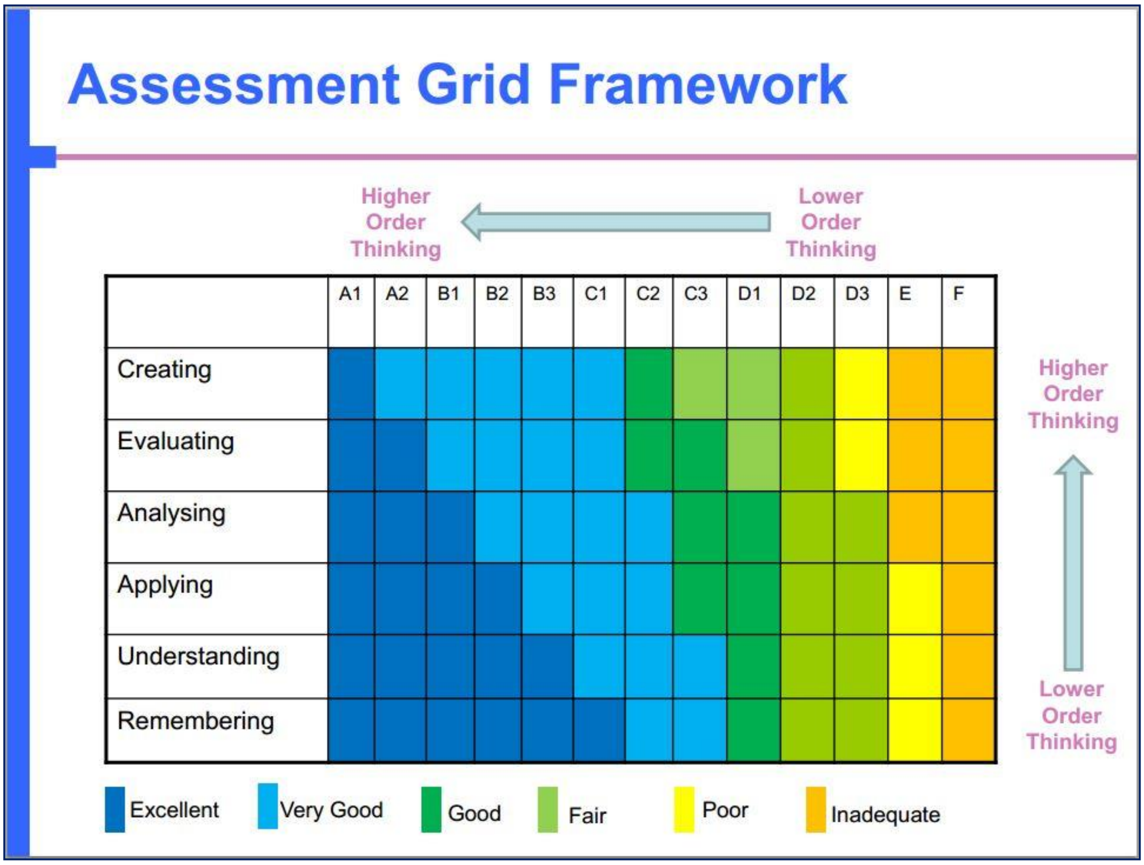


Figure 5-8 Assessment grid framework (Hyland, 2013)

Applying this framework would suggest that an A1 grade means that the student has excellent competence at all levels whereas an A2 they have excellent competencies at all levels as far as evaluating, but only very good competencies at creating. This grid requires further research to determine its validity when applied to the science subjects as in the current science syllabi, there are very few (if any) opportunities for students to be creative in examinations and yet approximately 10% of students taking for example physics, achieve an A1 in this subject.

5.3.5 Methodology to applying the framework

To place assessment items on the 3-axis scale of demand, each task is assigned numbers based on the three scales of assessment criteria, cognitive process and knowledge dimension. See Tables 5−5 and 5−6.

	Part of a question linked to a command term	**Point on scale**		
	Question	**A**	**K**	**C**
A= Assessment Criteria; **K**= Knowledge Dimension; **C**= Cognitive Domain.				

Table 5-5 Framework template

Assessment Criteria – written examination	Point on scale
Knowledge and understanding of facts principles concepts and methods	1
Application of knowledge to familiar and unseen contexts	2
Manipulation, analysis and evaluation of data	3
Use of arguments based on evidence	4
Knowledge Dimension	
Factual	1
Conceptual	2
Procedural	3
Metacognitive	4
Cognitive Process Dimension	
Remember	1
Understand	2
Apply	3
Analyse	4
Evaluate	5
Create	6

Table 5-6 Numbers allocated to levels

In assigning the codes for each section, the following guidelines were followed. The guidelines for applying the scale to tasks were as follows:

- The level reflects the complexity of the processes demanded by the task, rather than its difficulty. The level describes the kind of thinking required by a task, not whether or not the task is "difficult".
- If the task is between two levels, the higher of the two levels is assigned
- The command term alone is not sufficient information to assign a level. The context and the complexity of the task and/or information provided and the levels of students' prior knowledge are also considered.

Once the task has been assigned scales the task value is displayed in the three dimensional graphic.

Each task within a question is treated separately. The cognitive demand, the knowledge type and the assessment criterion are indicated on a table. For each task, the scores are represented in the table in two ways. First as the top level assigned in each of the categories, and second as the average level assigned in each of the categories. The choice of which graphic to use will depend on the type of information required about the question. The scores are visually represented on a three-dimensional graphic as in Figure 5−11.

5.3.6 Applying frameworks to sample questions

In this section, a Physics question, a Biology question and a Chemistry question are analysed using the framework according to the methodology given above. For ease of reading, the Figures are labelled according to Table 5.7.

Subject	Question	Analysis Grid	3-axis scale
Physics	Figure 5−9	Figure 5−10	Figure 5−11
Biology	Figure 5−12	Figure 5−13	Figure 5−14
Chemistry	Figure 5−15	Figure 5−16	Figure 5−17

Table 5-7 Labelling of figures

Flow occurs in many different areas of physics. For example, flow of electrons is an electric current; heat flow takes place as a result of a temperature gradient, and water or gas flow along pipes.

The dimensions of the material through which flow occurs, together with the properties of the material and the cause of flow, determine the amount of flow that takes place.

Section A

1 Explain why one pipe is necessary for the supply of gas to a house but two cables are necessary for the supply of electricity.

2 The rate of flow of heat energy through the wall of a room is given by

$$\frac{Q}{t} = k\,A\left(\frac{\theta_2 - \theta_1}{d}\right)$$

Where:

Q = the quantity of heat energy;

t = time;

k = a constant called the thermal conductivity;

A = the surface area of the wall;

d = is the thickness of the wall;

θ_2 and θ_1 = the inside and outside temperatures respectively.

i) Deduce the SI unit of *k*.

ii) The temperature inside a room is 22.0 *°C* and the outside temperature is 8.0 *°C*. The value of *k* for the wall of the room is 0.35 in SI units. Calculate the rate of flow of heat energy through $1\ \mathrm{m}^2$ of the wall given that the wall is 15 cm thick.

iii) Sketch a graph to illustrate how the rate of heat flow across the wall varies with the wall's thickness, d, if all other values remain unchanged.

Section B

1 Write an equation (analogous to that in section A question 2) for the rate of flow of charge through a wire($\frac{Q}{t}$). Your equation should include terms for potential difference across the wire (V), the resistivity of the material of the wire (ρ), and the length (ℓ) and cross-sectional area (A) of the wire.

2 By comparing the equations in sections A question 2 and B question 1, state which thermal property corresponds to:

i) V

ii) ρ

3 The rate of flow of gas through a pipe ($\frac{\mathrm{V}}{\mathrm{t}}$) may be measured in $cm^3\ s^{-1}$.

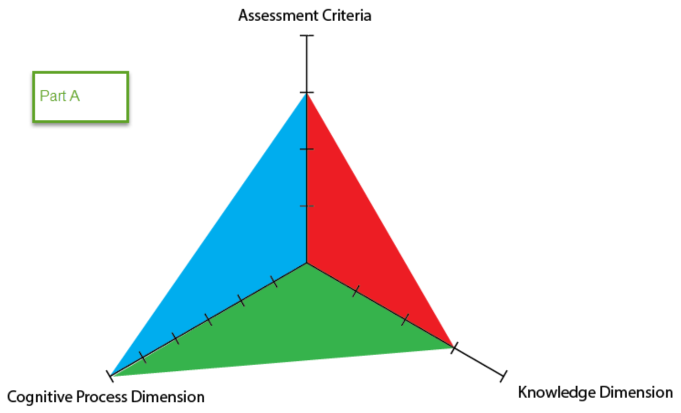
By analogy, suggest an equation for the rate of flow of gas. State the meaning of any symbols you introduce.

Figure 5-9 Physics question

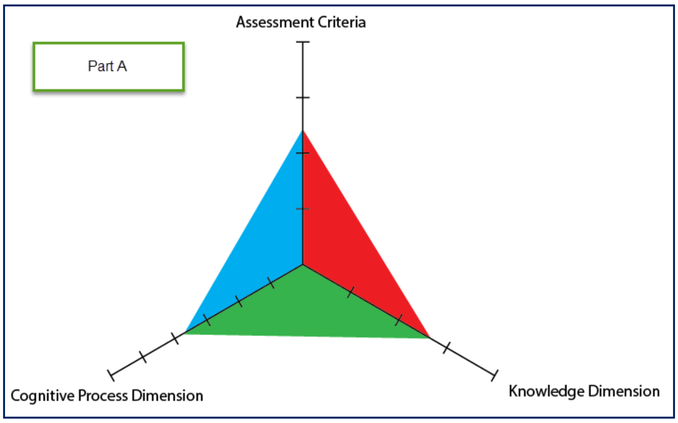
	Part of a question linked to a command term	Point on scale		
	Question	**A**	**K**	**C**
A 1	Explain why one pipe is necessary for the supply of gas to a house but two cables are necessary for the supply of electricity.	**2**	**2**	**3**
A2(i)	Deduce the SI unit of *k*.	**3**	**3**	**3**
A2(ii)	Calculate the rate of flow of heat energy through $1\ \mathrm{m}^2$ of the wall given that the wall is 15 cm thick.	**1**	**3**	**3**
A2(iii)	Sketch a graph to illustrate how the rate of heat flow across the wall varies with the wall's thickness, d, if all other values remain unchanged.	**3**	**3**	**6**
	Highest A	**3**	**3**	**6**
	Average A	**2.5**	**2.75**	**3.75**
B 1	Write an equation (analogous to that in section A question 2) for the rate of flow of charge through a wire $(\frac{Q}{t})$.	**3**	**3**	**4**
B2	By comparing the equations in sections A question 2 and B question 1, state which thermal property corresponds to: i.) V; Iii) ρ	**2**	**2**	**3**
B3	The rate of flow of gas through a pipe $(\frac{\mathrm{V}}{\mathrm{t}})$ may be measured in $cm^3\ s^{-1}$. By analogy, suggest an equation for the rate of flow of gas. State the meaning of any symbols you introduce.	**2**	**4**	**6**
B4	160 $cm^3\ s^{-1}$ of gas flows through a pipe of internal diameter 15.0 mm. Calculate the rate of flow of gas through a pipe of internal diameter 22.5 mm under the same conditions.	**2**	**3**	**3**
	Highest B	**3**	**4**	**6**
	Average B	**2.25**	**3**	**4**

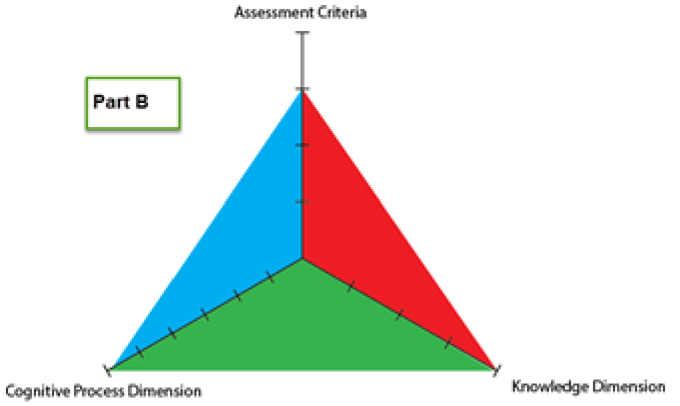
Figure 5-10 Framework applied to physics question

Highest Demand



Average demand





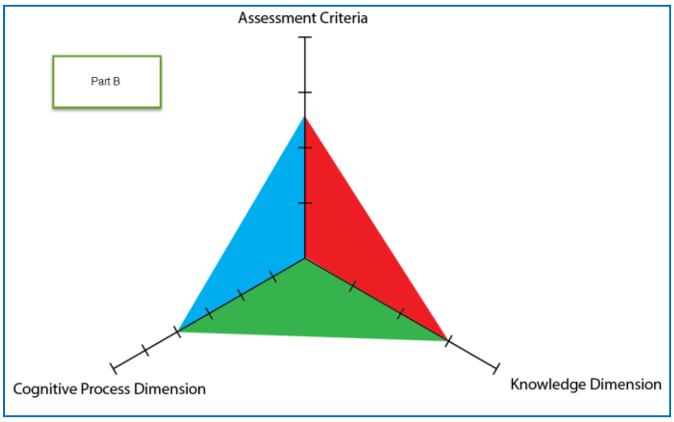
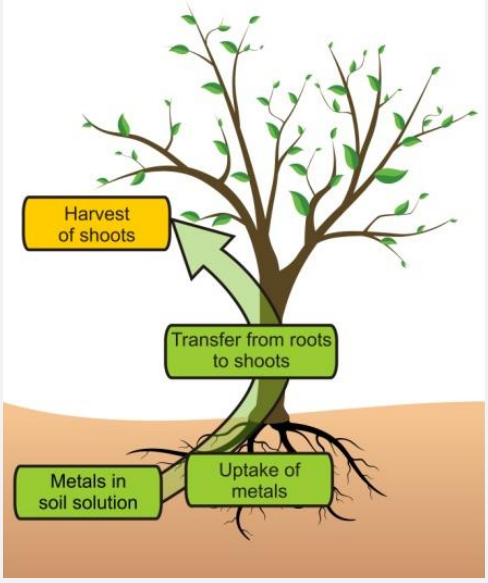


Figure 5-11 Physics question framework level graphic

Heavy Metal Soil Contamination and Phytoremediation

The ecological use of the term "heavy metals" usually refers to metallic soil water and sludge contaminants, such as lead, cadmium, mercury, arsenic and copper, amongst others.



Mining and heavy industry have historically been causes of heavy metal contamination in the environment. Efforts to clean polluted areas can be costly, but necessary.

Green plants and their associated microorganisms are used to clean up contaminated land in a process called Phytoremediation. Plants growing on contaminated soils can either take up large amounts of the metal into the above ground biomass (accumulators), or can block the transport of metals between roots and shoot (excluders). Accumulator plants have the facility to concentrate metals from soils that contain low as well as high concentrations of metals. Plants that show exceptional uptake of metals are known as hyperaccumulators.

Two values are used for the purpose of comparing individual species capability to act as phytoremediation agents: the *bioconcentration factor*, BCF, and the *translocation factor*, TF.

$BCF = \frac{\text{Concentration of heavy metals in the shoot}}{\text{Concentration of heavy metals in the soil}}$	$TF = \frac{\text{Concentration of heavy metals in the shoot}}{\text{Concentration of heavy metal in the root}}$

These ratios give an indication of how effective a plant is at extracting heavy metals from the soil *(BCF)*, and of transferring the absorbed heavy metals to the shoot *(TF)*.

Section A

One study examined the mass of cadmium taken up by five different species of flowering plants. Some of the data is shown in **Table 1**. All of the specimens were grown for 35 days in pots of loamy soil artificially contaminated with cadmium at a concentration of 17.6 mg per kilogram of soil. The root and shoot cadmium concentrations were then measured.

Table 1 Concentration of cadmium in roots and shoots of selected species.

Species	**Root conc. of cadmium mg kg^{-1}**	**Shoot conc. of cadmium mg kg^{-1}**	**BCF**	**TF**
Star cluster	18.9	10.7		
French marigold	11 3.0	66.3		
Impatiens	99.0	100.0		
Garden verbena	49.5	7.6		
Scarlet sage	71.0	30.8		

1. Calculate the values for the bioconcentration factor, BCF, and the translocation factor, TF, for each of the species shown above.
2. A clean-up project using phytoremediation has been proposed for a site needed for a new school. Determine which of the species in this study would be the most likely candidate for the project.
3. An ecologist proposes that the highest score for the translocation factor would automatically make that species the plant of choice for the clean-up, as only the shoot can be quickly and easily harvested. Evaluate the strength or weakness of this argument.

Section C

Having seen a YouTube video on phytoremediation of bare patches of land near abandoned copper mines on Parys Mountain in Anglesey, a group of students chose to carry out a research project on copper tolerance in *Sinapis alba*, the white mustard plant.

They placed seeds on filter paper, dampened with solutions of copper sulphate of different concentrations, in germinating chambers and placed these under a light bank for five days. They then measured the lengths of roots and shoots and graphed these as a function of copper concentration. The results are displayed in **Figure 1**.

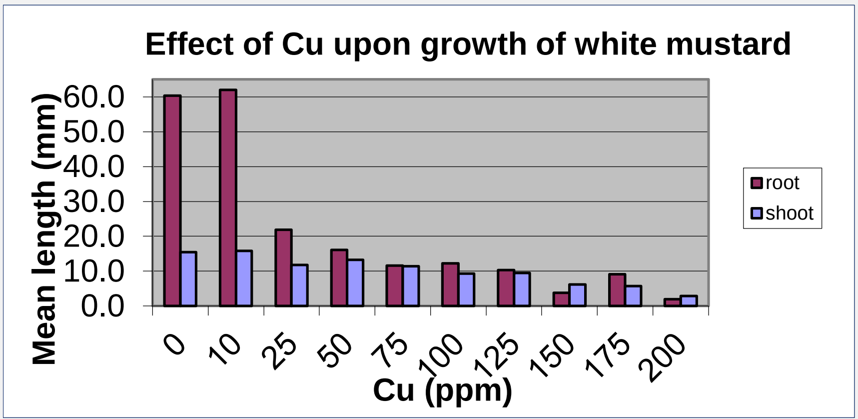


Figure 1

The students concluded *Sinapis alba* is, indeed, copper tolerant.

1. Suggest changes to the design of their experiment that would enable them to draw conclusions based upon more solid evidence.
2. Explain how copper tolerance could be of a selective advantage to a plant near one of the abandoned copper mines on Parys Mountain.

Figure 5-12 Biology question

	Part of a question linked to a command term	Point on scale		
	Question	**A**	**K**	**C**
A1	Calculate the values for the bioconcentration factor, BCF, and the translocation factor, TF, for the species shown above.	**2**	**2**	**3**
A2	Determine which of the species in this study would be the most likely candidate for the project.	**3**	**2**	**4**
A3	Evaluate the strength or weakness of this argument.	**4**	**4**	**5**
	Highest demand	**4**	**4**	**5**
	Average demand	**3**	**2.7**	**4**
B1	Present this data in a suitable graphical form.	**2**	**3**	**2**
B2	Compare the performance of varieties A and B, and hence consider the judgment made in your answer to question 2 above: justify a delay in the clean-up project while further research is undertaken.	**4**	**4**	**5**
	Highest demand	**4**	**4**	**5**
	Average demand	**3**	**3.5**	**3.5**
C1	Suggest changes to the design of their experiment that would enable them to draw conclusions based upon more solid evidence.	**2**	**2**	**6**
C2	Explain how copper tolerance could be of a selective advantage to a plant near one of the abandoned copper mines on Parys Mountain.	**2**	**2**	**2**
	Highest demand	**2**	**2**	**6**
	Average demand	**2**	**2**	**4**

Figure 5-13 Framework applied to biology question

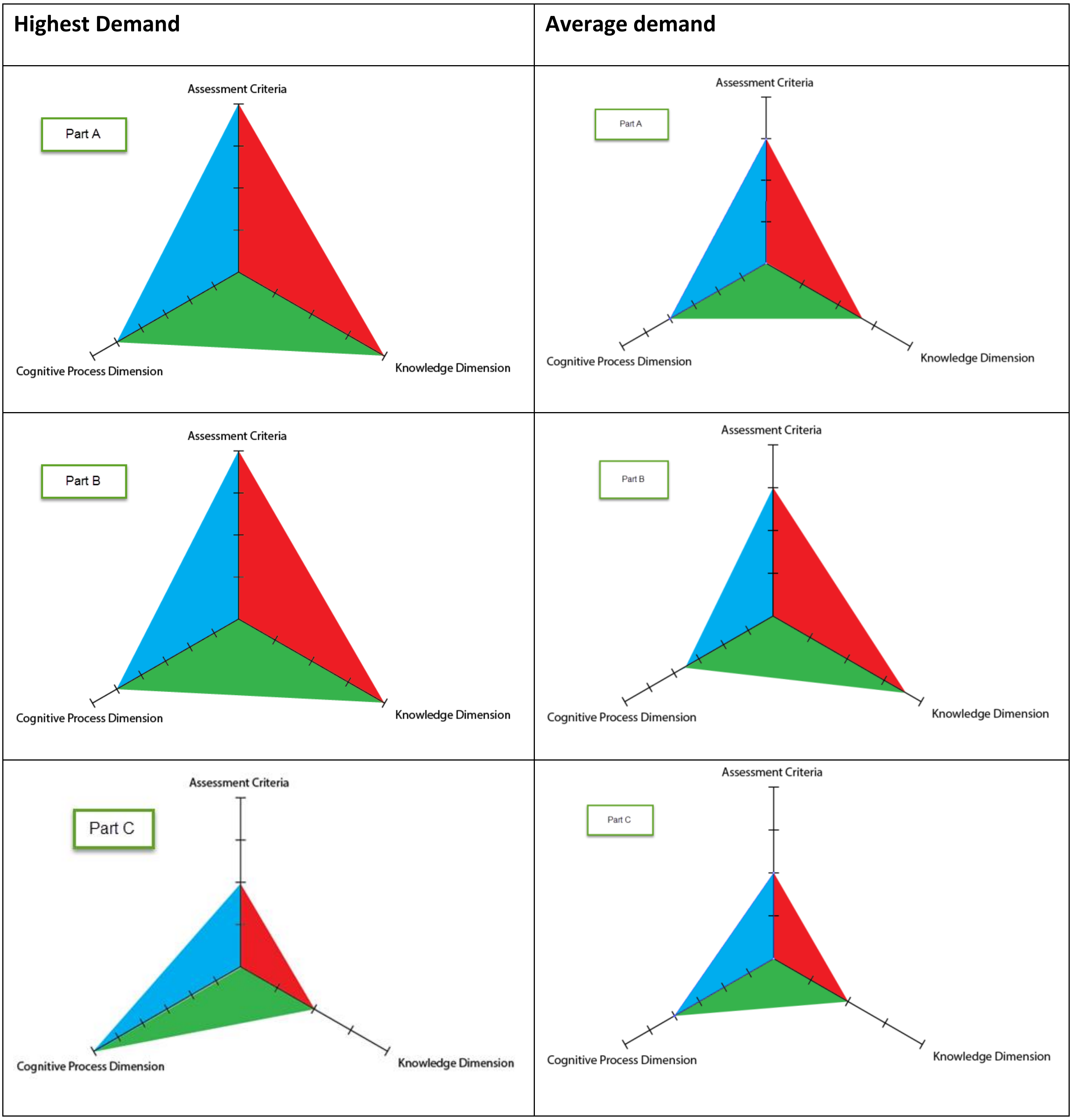
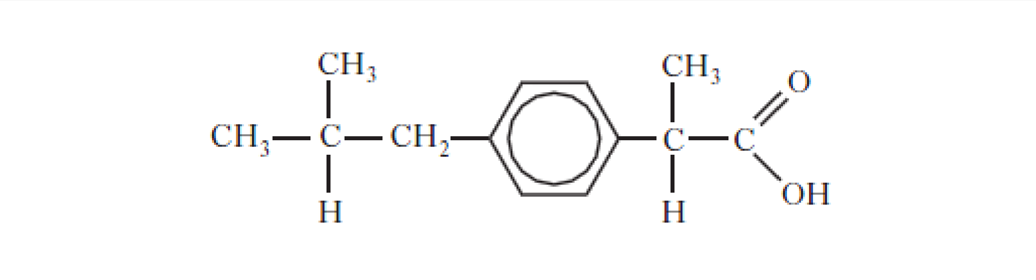


Figure 5-14 Biology framework levels graphic

Chemistry question

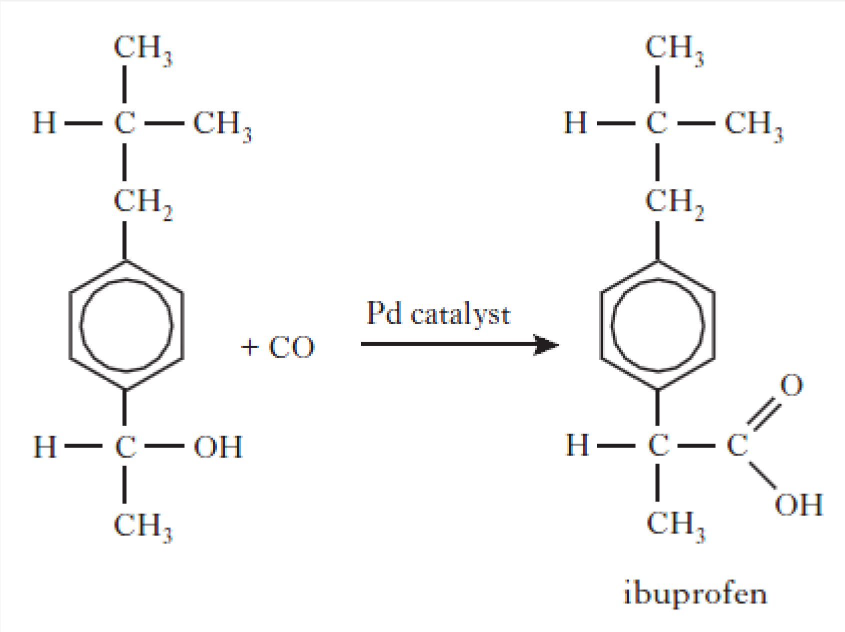
Section A

Ibuprofen is a best-selling pain killer.



Ibuprofen tablets should not be used by people who suffer from acid indigestion. Name the functional group present in ibuprofen that makes this drug unsuitable in these patients.

From the 1990s ibuprofen has been synthesised by a three step process. The equation below shows the final step of this synthesis.

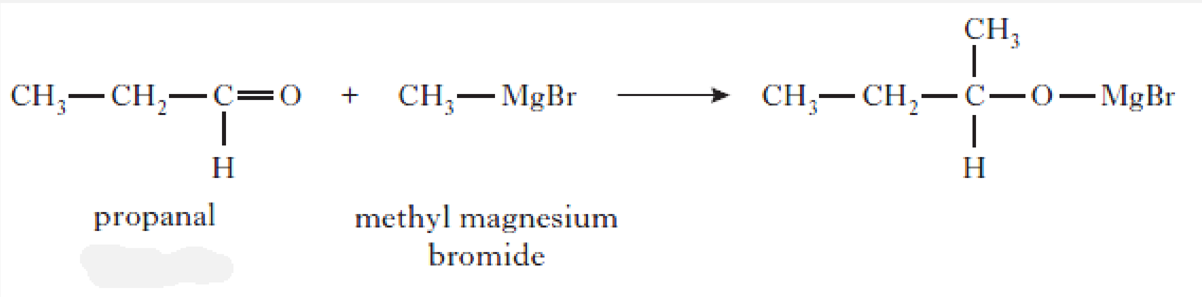


1. What is the atom economy of this step?

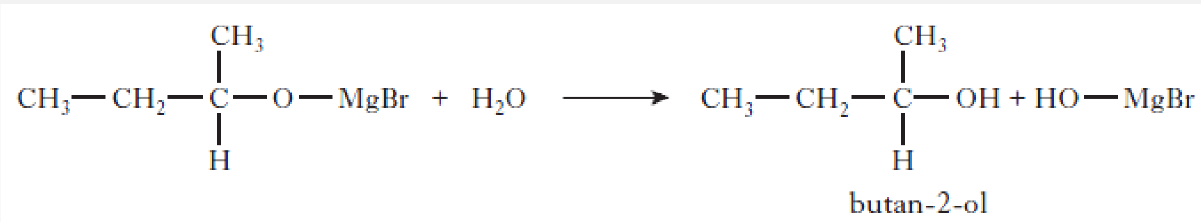
Section B

1. Butanone is an important solvent. Butan-2-ol is required for its production. Name the type of reaction that takes place when butan-2-ol is converted into butanone.
2. A chemist tested whether it would be possible to make money by producing butan-2-ol from propanal using a two-step process.

Step One: Methyl magnesium bromide reacts with propanal.



Step two: The product from step one reacts with water to produce butan-2-ol



The chemist managed to make 5.75g of butan-2-ol using 5.01g of propanal and 20.0g of methyl magnesium bromide. The costs of the chemicals are shown below:

Chemical	Cost
Propanal	€ 22.10 for 1kg
Methyl magnesium bromide	€ 75.00 for 25 kg

i. Calculate the cost of the chemicals needed to produce 100g of butan-2-ol using this method.

ii. Calculate the percentage yield assuming that the CH_3MgBr is in excess.

iii. Suggest one alteration to the quantity of either propanal or methyl magnesium bromide used which might reduce the cost of producing butan-2-ol.

Section C

The industrial method currently used to produce butan-2-ol is the hydration of but-2-ene

$C_4H_8(g) + H_2O(g) \longrightarrow C_4H_{10}O(g)$

The enthalpy values for the following reactions are:

$4C(s) + 4H_2(g) \longrightarrow C_4H_8(g)$	ΔH=-7.1 $kjmol^{-1}$
$4C(s) + 5H_2(g) + 1/_2O_2(g) \longrightarrow C_4H_{10}(g)$	ΔH=-292.8 $kjmol^{-1}$
$42H_2(g) + O_2(g) \longrightarrow 2H_2O(g)$	ΔH=-48 3.6 $kjmol^{-1}$

1. Using the data above, calculate the enthalpy change, in $kjmol^{-1}$, for the production of butan-2-ol by hydration of but-2-ene.

Figure 5-15 Chemistry question

Applying the chemistry question to the 3 axis scale of demand

	Part of a question linked to a command term	**Point on scale**		
	Question	**A**	**K**	**C**
A1	Name the functional group present in ibuprofen that makes this drug unsuitable in these patients.	**1**	**1**	**1**
A2	What is the atom economy of this step?	**3**	**3**	**3**
	Highest demand	**3**	**3**	**3**
	Average demand	**2**	**2**	**2**
B1	Name the type of reaction that takes place when butan-2-ol is converted into butanone.	**1**	**2**	**2**
B2 (i)	Calculate the cost of the chemicals needed to produce 100g of butan-2-ol using this method.	**3**	3	**3**
B2 (ii)	Calculate the percentage yield assuming that CH_3MgBr is in excess.	3	**3**	**3**

	Part of a question linked to a command term	Point on scale		
B2 (iii)	Suggest one alteration to the quantity of either propanal or methyl magnesium bromide used which might reduce the cost of producing butan-2-ol.	**2**	**2**	**2**
	Highest demand	**3**	**3**	**3**
	Average demand	**2.25**	**2.5**	**2.7**
C	Using the data above, calculate the enthalpy change, in $kjmol^{-1}$, for the production of butan-2-ol by hydration of but-2-ene.	**3**	**3**	**3**
	Highest demand	**3**	**3**	**3**
	Average demand	**3**	**3**	**3**

Figure 5-16 Chemistry question framework

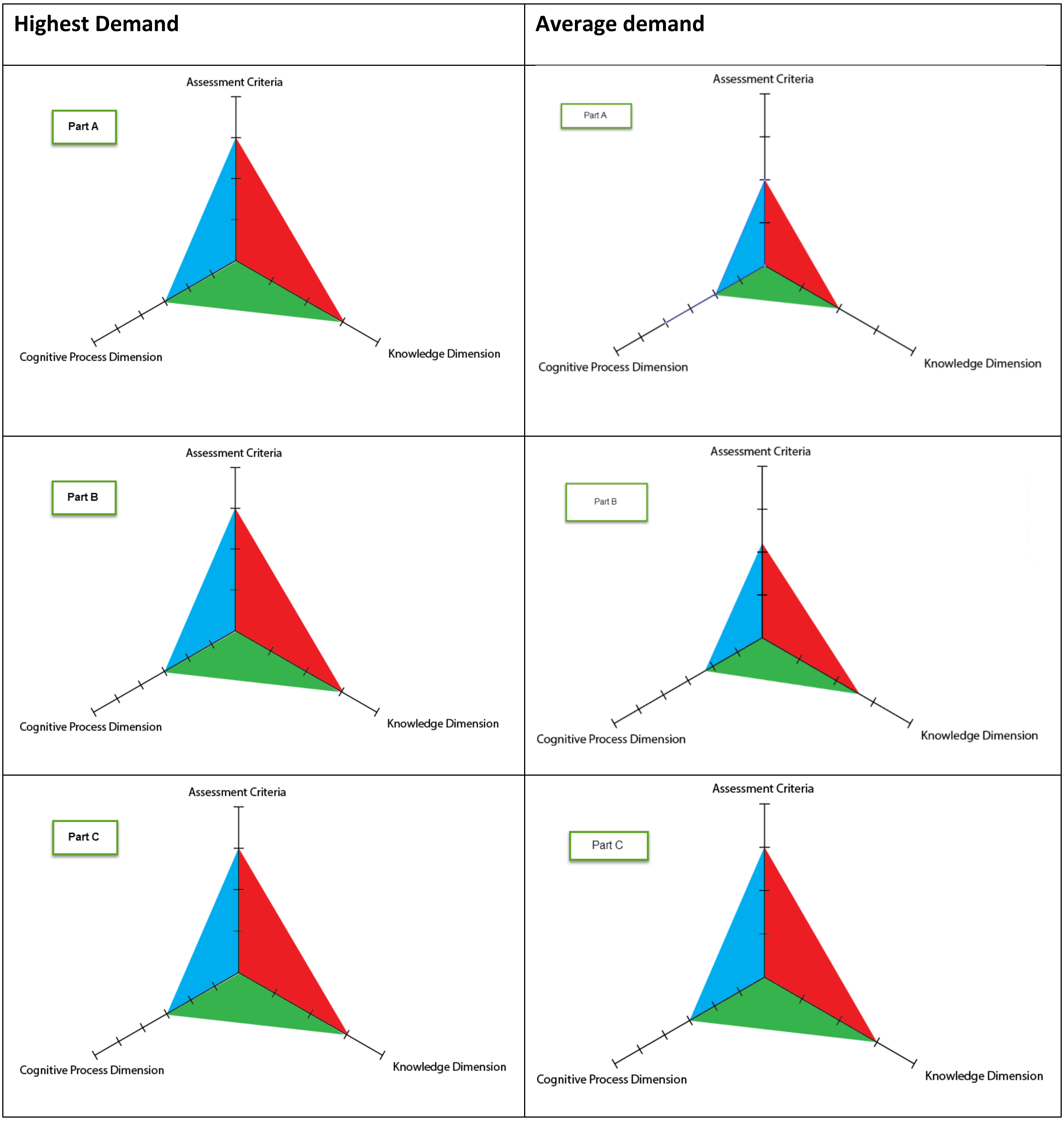


Figure 5-17 Chemistry framework levels graphic

5.3.7 Using the 3-axis scale framework to compare questions

Two chemistry questions were compared using the framework. The first question (QUESTION X: Figure 5−18) is a standard LC question on organic chemistry. The second question (QUESTION Y: Figure 5−21) is one that had been written as part of PhD research (Rice, Nolan & Finlayson, 2015); the question was designed to assess higher order skills. QUESTION X was considered a *difficult* question in LC. The QUESTION Y was very straightforward, and aligns directly with learning outcomes from the revised specification.

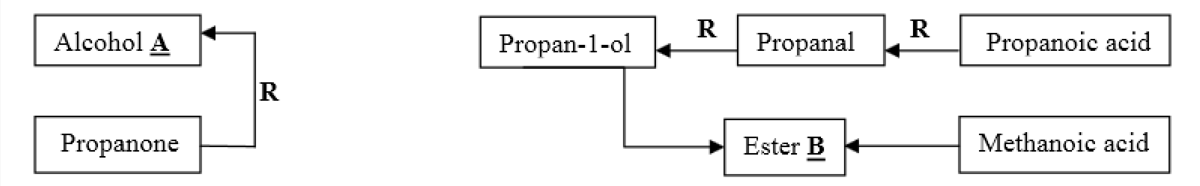
The analysis of QUESTION X is shown in Figure 5−19 and shown as a 3-axis diagram in Figure 5−20. Likewise, QUESTION Y is shown in Figures 5−21, 5−22 and 5−23.

The framework was applied to both questions and the results compared. From the analysis, QUESTION X, although difficult, was not cognitively demanding, Figure 5-20. While QUESTION Y, although very straightforward, was cognitively very demanding (Figure 5-23).

QUESTION Y is a straightforward question; it would not be considered difficult. However, students must generate answers to these questions based on their understanding of chemistry rather than on recall of facts. The diagrams show that this question is cognitively demanding, despite the fact that it is straightforward and uncomplicated.

QUESTION X

Study the reaction scheme and answer the questions that follow.



i) Give the systematic (IUPAC) name for (i) the alcohol **A**, (ii) the ester **B**.

ii) Alcohol A and propan-1-ol are structural isomers. Explain the underlined term

iii) What is the structural difference between a primary alcohol and a secondary alcohol?

iv) Identify another pair of structural isomers from the reaction scheme.

v) Identify a compound in the scheme whose carbon atoms are all in tetrahedral geometry.

vi) Name the reagent and catalyst used to bring about the conversions labelled **R**.

vii) Propanol is oxidised by Fehling's reagent. Describe how this reaction is carried out.

viii) Why does propane not react with Fehling's reagent?

ix) Which compound in the scheme would you expect to have a fruity odour?

Figure 5-18 QUESTION X (taken from Question 8 LCH chemistry examination 2012 (SEC, 2012b)

The framework applied to question X.

	Question	**A**	**K**	**C**
A i)	Give the IUPAC name	**1**	**1**	**1**
A ii)	Explain the underlined terms	**1**	**1**	**1**
A(iii)	What is the structural difference	**1**	**2**	**2**
	Identify another pair of structural isomers	**2**	**2**	**2**
	Level A	**2**	**2**	**2**
B(i)	Identify a compound with tetrahedral carbons	2	2	2
B (ii)	Name the reagent	1	1	1
B (iii)	Describe the oxidation reaction	1	**1**	**1**
B(iv)	Why does propanone not react with Fehling's reagent	1	**1**	**1**
B(v)	Which compound has a fruity odour	1	**2**	**1**
	Level B	2	**2**	**2**

Figure 5-19 Analysis framework applied to question X

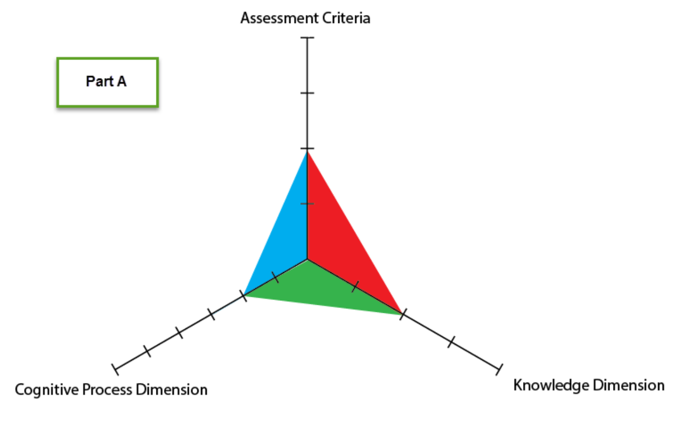
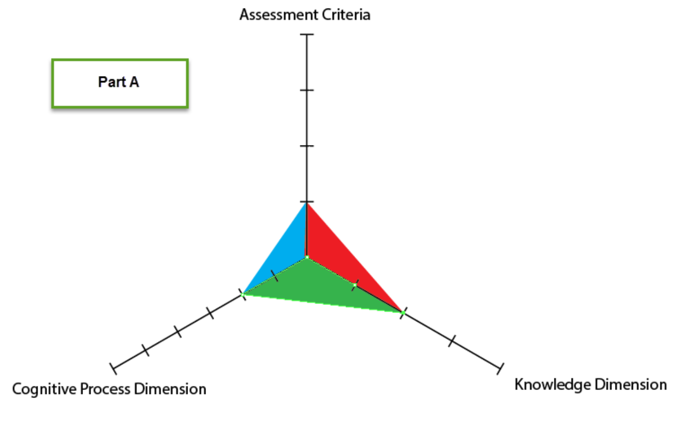
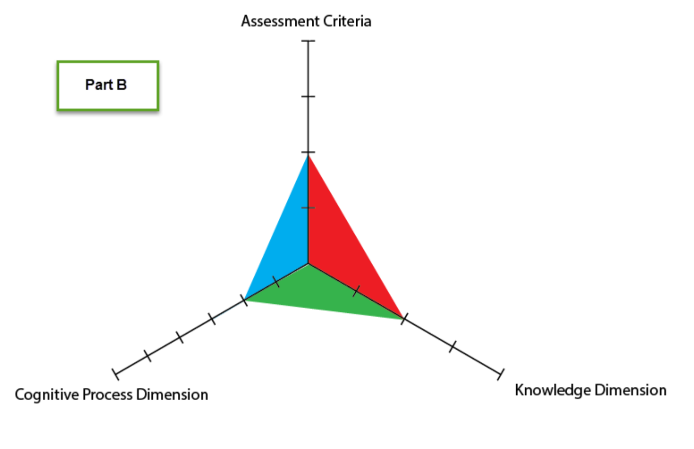
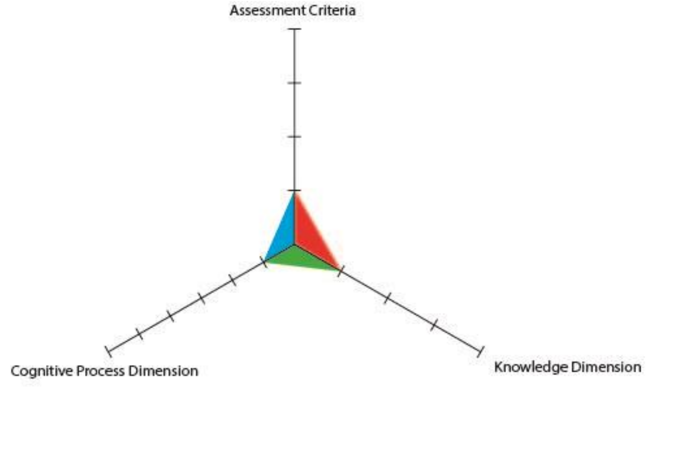
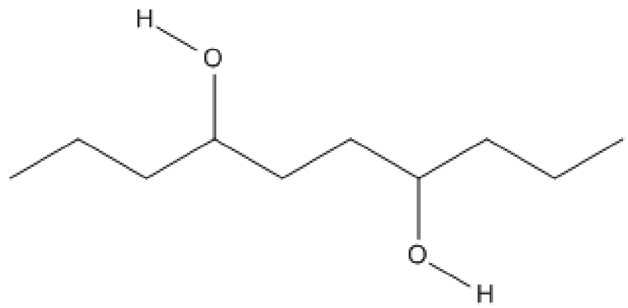
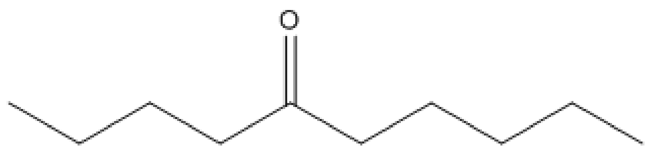
Highest Demand	**Average demand**
	
	

Figure 5-20 Question X framework levels graphic

CHEMISTRY QUESTION Y

Part A

For the following molecules:

A.	
B.	
C.	

i) Identify the electron rich and electron poor centres, i.e. assign δ^+ and δ^-, to the organic molecules above

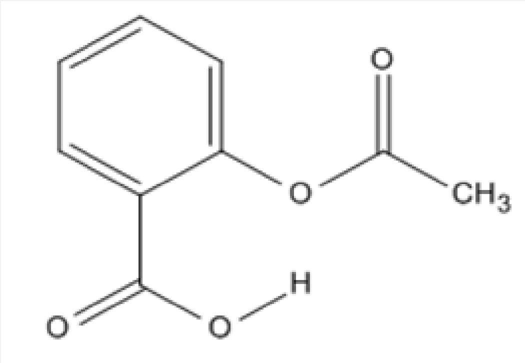
ii) Rank the organic molecules in order of increasing boiling point in the table below.

Lowest boiling point	
Highest boiling point	

iii) Explain your answer to part ii)

Part B

Acetylsalicylic acid, also known as Aspirin, is a common pain killer. Its structure is shown below:



i) Identify the electron rich and electron poor centres in Acetylsalicylic acid, i.e.: assign δ+ and δ- to the structure above

Redraw the structure of acetylsalicylic acid.

ii) If OH^- is added to the molecule, identify the reactive centres of the molecule, i.e.: where in the molecule is the OH^- likely to react with.

iii) Label the reactive centres 1, 2, 3, etc.

iv) Propose which react centre you believe is <u>most likely</u> to react with the OH, explain your reasoning.

Figure 5-21 QUESTION Y: Chemistry question – revised specification

	Question	A	K	C
A i)	Identify the electron rich and electron poor centres to the organic molecules	**3**	**2**	**4**
A ii)	Rank the order of increasing boiling point	**3**	**3**	**4**
	Explain your answer to ii)	**4**	**2**	**6**
	Highest demand	**4**	**3**	**6**
	Average demand	**3.3**	**2.3**	**4.6**
B(i)	Redraw	**2**	**3**	**2**
B (ii)	Label reactive centres if OH- is added	**3**	3	**5**
B (iii)	Propose which react centre is most likely to react with the OH^-explaining your reasoning	4	**2**	**6**
	Highest demand	4	**3**	**6**
	Average demand			

Figure 5-22 QUESTION Y framework levels

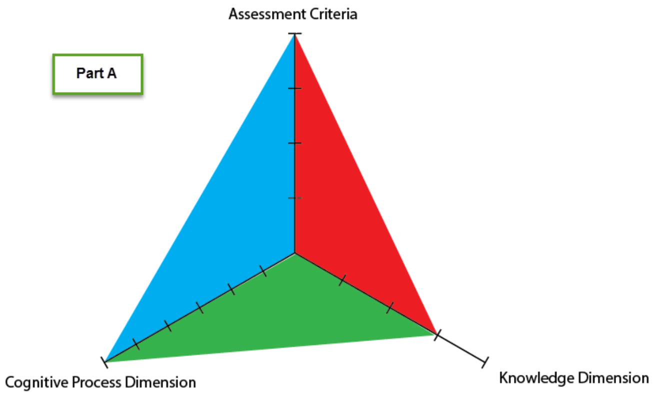
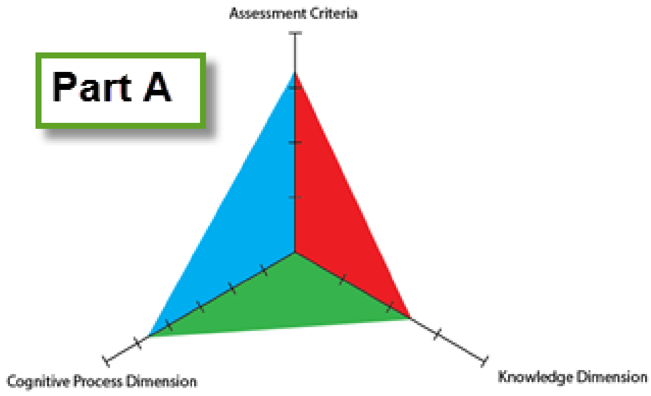
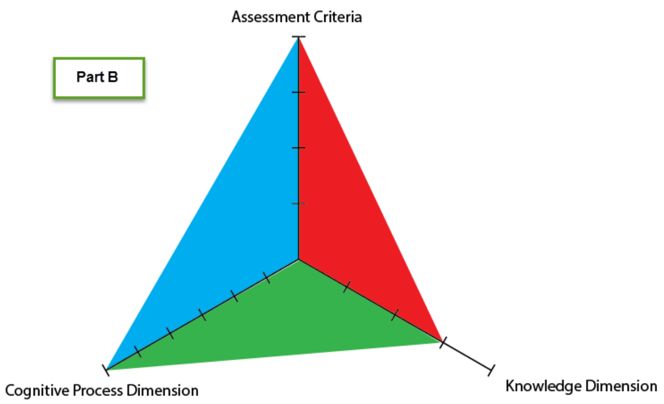
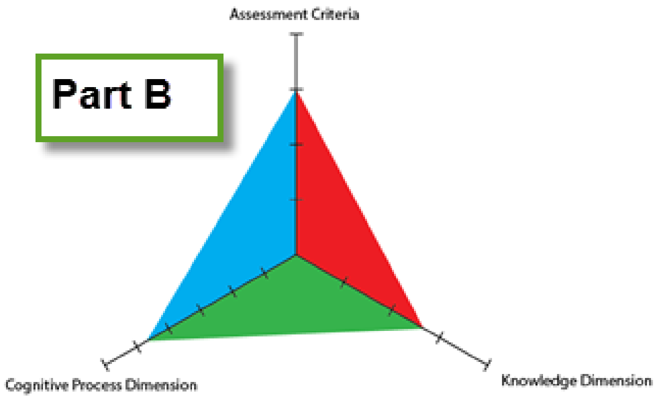
<table>
<tr><th>Highest Demand</th><th>Average demand</th></tr>
<tr><td>
</td><td>a

</td></tr>
<tr><td>
</td><td>
</td></tr>
</table>

Figure 5-23 QUESTION Y framework levels graphic

5.4 Conclusion

Assessment is a critical tool for learning. Used positively it has the potential to support the kinds of changes to teaching and learning that are appropriate for 21st Century learners.

To date in Ireland Leaving Certificate assessment has been hostage to the syllabus, as examiners have been very restricted in the types of questions that they could set. This was particularly true of assessment of practical science, where the assessment was restricted to mandatory practical activities. Revision of the Leaving Certificate sciences offers a timely opportunity for the introduction of innovative assessments to drive change. Change will only succeed if teachers believe that the change is right and appropriate for their students. It is important therefore, that teachers fully understand the complex nature of the learning outcomes so that they can construct measures to validly assess the learning that has taken place for students to achieve those learning outcomes. Researchers and test setters use a variety of assessment frameworks to measure demands of assessment. A framework, based on the framework for learning outcomes was constructed to help teachers to target specific areas of learning. The framework is simplistic in its design, but it facilitates the mapping of assessment items so that, over time, and over a range of items, teachers can be confident that they have assessed an appropriate range of knowledge and skills, and that all of the assessment criteria are being met.

6 Supporting curriculum development

If the revised specification is to be implemented as intended by the curriculum developers, teaching and learning will have to change significantly. Students will be expected to engage with content at a much deeper level than previously, as they work within a set of defined scientific practices. They will be expected to develop skills, and show through their performance that they have a mastery of those skills, as they apply their science knowledge and understanding. As part of the curriculum development process, groups of teachers collaborated in two design research projects that aimed to illustrate what these changes would look like in practice. The first project entitled *Asteroids, Impacts and Craters* was initiated as part of the work with teachers. The aim of this project was to show what key skills, including higher order thinking skills embedded in learning outcomes, look like in classroom practice. The second project, entitled *Assessment of practical science* provided examples of different ways of assessing practical science to support the discussions and deliberations of the curriculum developers on how practical assessment could work.

Acknowledging that engagement with schools and teachers would inform, and ultimately enhance the design and development of the Leaving Certificate science specifications, the two projects, *Asteroids Impacts and Crater*s and *Assessment of Practical Scienc*e used a model of educational design based research, defined as the systematic study of designing, developing and evaluating educational programs, processes and products (van den Akker, Gravemeijer, McKenney, & Nieveen, 2006). The most compelling reason for educational design based research is to increase the relevance of research for educational policy and practice and to strengthen the relationships between curriculum research, policy and practice. Section 6.1 below discusses the design –based research method.

6.1 Design based research method for project work with schools

Design based research in education, is intervention research designed to inform practice. Researchers work with practitioners and other experts to engineer innovative educational environments while simultaneously trying them out in the complex dynamic setting of a real classroom. Design based research is used to co-develop theories with practitioners that target domain specific learning processes. A design scientist in the field of education engineers innovative educational environments whilst simultaneously conducting experimental studies on those innovations.

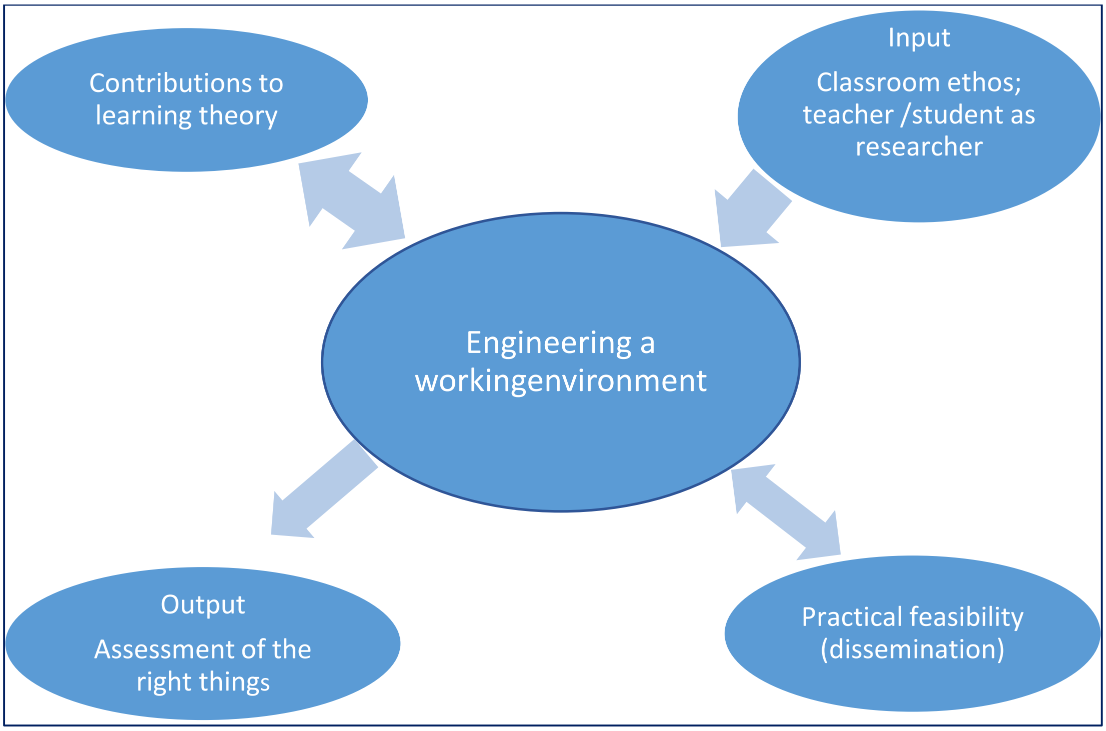


Figure 6-1: The complex features of design experiments (Brown 1992).

Central to the design experiments, is that the classroom must function as a working environment (Figure 6−1); very often in education research, different aspects are treated independently, yet you cannot make changes to one without distortion to other aspects(A. L. Brown, 1992). The inputs and the outputs are engineered along with the teacher/student interactions and the implications for assessment. And importantly the practical feasibility is equally important as the contribution to learning theory.

Design based research has been gaining momentum in the field of educational studies, one to be noted in particular is the work by Van den Akker and his colleagues in the Netherlands. In Educational Design Research, Van den Aker et al. describe development research as

> *a particular type of educational design research that addresses curricular problems, essentially in dealing with changing aims and contents of learning that inform and support decision-making in the process of curriculum development (Van den Akker et al. 2013).*

He suggests that the emphasis in this approach is better described as research based development, rather than design-based research. Van den Aker argues that a better cross-fertilization between educational research and curriculum development may strengthen the information base for curriculum policies and classroom practice.

Design research is used as a common term for a set of related research, for example: design experiments (Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003)(A. L. Brown, 1992) design studies (Shavelson, Phillips, Towne, & Feuer, 2003) design-based research(Design Based Research Collective, 2003), developmental research (Lijnse, 1995). Although the methods of design research vary, it is used when there is an open problem that is hard to define. Van den Akker uses the following definition:

> *to design and develop an intervention (such as programs, teaching-learning strategies and materials, products and systems) as a solution to a complex educational problem as well as to advance our knowledge about the characteristics of these interventions and the processes to design and develop them, or alternatively to design and develop educational interventions (about for example, learning processes, learning environments and the like) with the purpose to develop or validate theories. (van den Akker et al., 2013)*

The reasons for engaging in design-based research are to bring the research closer to practice and to provide strategies to help to overcome or lessen difficult obstacles in educational progress.

The Design-Based Research Collective states that:

> *Educational research is often divorced from the problems and issues of everyday practice – a split that resulted in a credibility gap and creates a need for new research approaches that speak directly to problems of practice and that lead to the development of 'usable knowledge' (Design-Based Research Collective 2003).*

The definition above, and the need to develop useable knowledge developed through practice by practitioners resonates well with the NCCA policy of working with teachers and schools to support curriculum development. The concept of design research was particularly appropriate for the development of the revised science curricula. One of the principle reasons is that there was a sense that, whilst all of the education partners were aware of the significant problems associated with introducing such huge change at a time when teachers were already under pressure from perceived overload, they could not see how the problems could be overcome, yet they were adamant that change of the scale proposed was essential to bring science education in Ireland into line with international standards.

Cobb and Jackson point to the importance of establishing *research-practitioner partnerships* that involve co-designing, testing, and refining current school and district design conjectures and emphasise the necessity of conducting *systematic inquiry* to develop theory related to improving quality of classroom instruction and student learning at the system level (Cobb & Jackson, 2011).

Pepin & Nieveen (2013) describe the disconnect between policy, practice and research as a *trilemma of different worlds* (Figure 6−2). School-based curriculum development and teacher development can be very site-specific, without analysing the evidence from research. Likewise, policy development sometimes concentrates on quick-fixes, often in response to political pressure. They suggest that design-based research can be used to combine the thinking of policy makers, the evidence from research and the experience of practitioners. Van den Akker supports this view and suggests that this type of research can provide more useful solutions for practical curriculum development than many traditional research approaches such as experiments, surveys, correlational analyses (van den Akker, 1998).

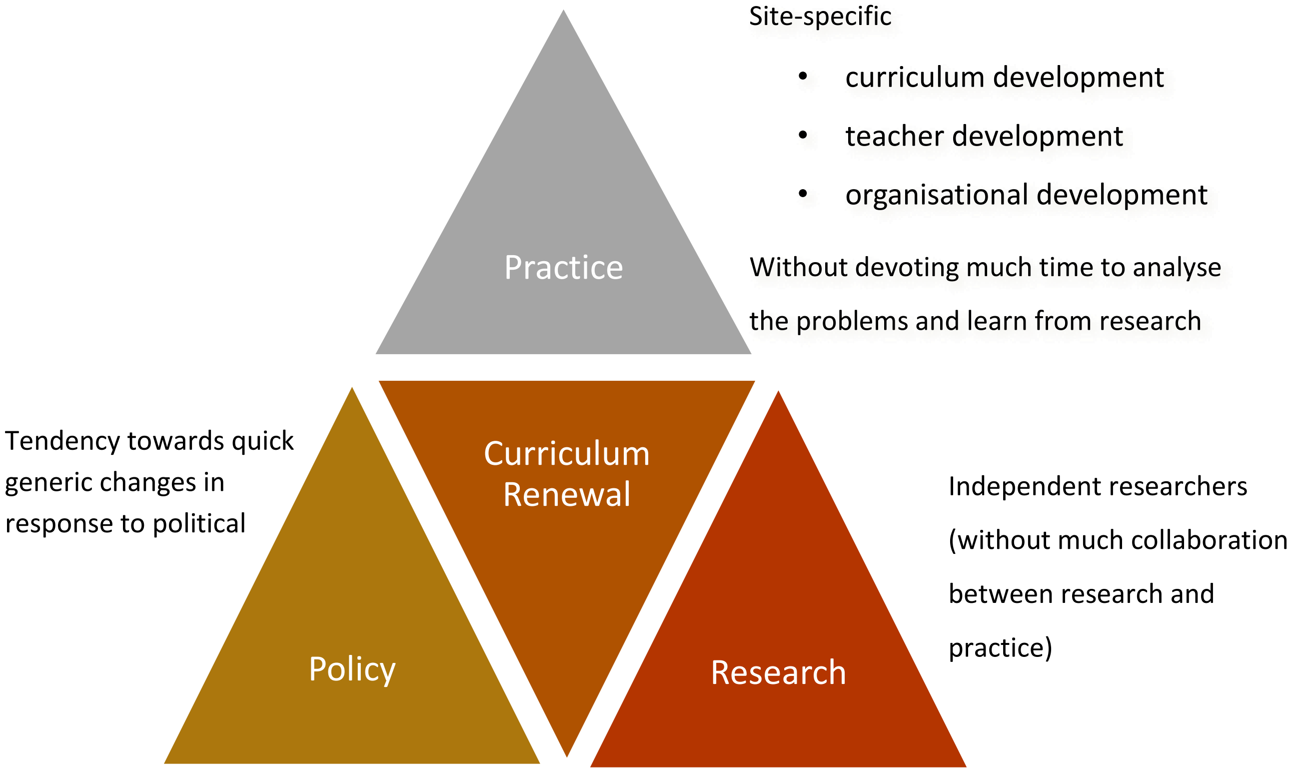


Figure 6-2 Trilemma of different worlds (Pepin & Nieveen 2013)

The research–based project cycle is designed with the help of education research experts, researchers work with teachers who enact the design, the enactment is analysed and reflected on, and the design is adapted as necessary (Figure 6–3).

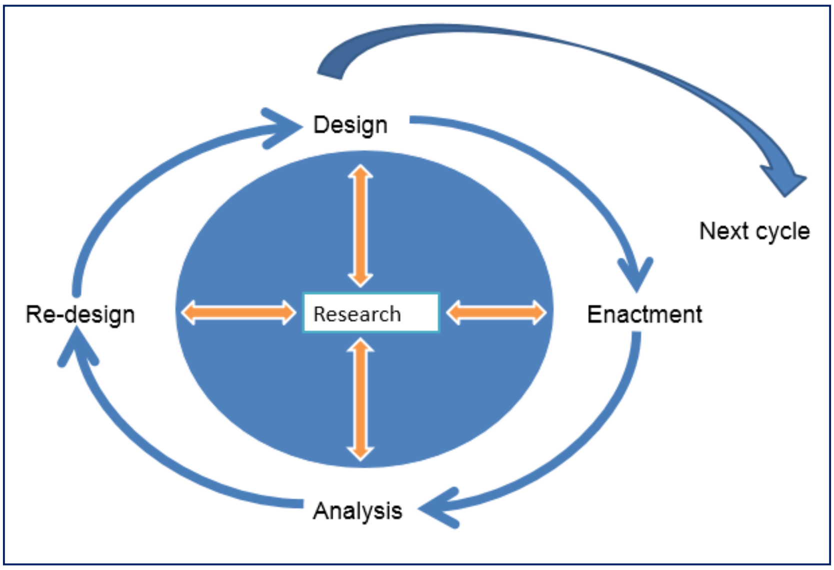


Figure 6-3 Design-based research cycle (Pepin & Nieveen. 2013)

The methodologies and the curriculum materials to support learning, all form part of the cycle. In her book*, The Teacher-Tool Relationship: Theorizing the Design and Use of Curriculum Materials,* Brown compares the relationship between teachers and curriculum materials to those of musicians and their music; the same song played by different musicians takes on its own character, likewise, teachers interpret and adapt curriculum materials in ways that make their practice unique, even if there are similarities across classrooms (M. W. Brown, 2009).

Teachers work with curriculum materials, text books and other support structure (Figure 6‒4). In this participatory relationship, both the teacher and curriculum materials are active participants in the design of the planned curriculum and co-constructors (with students) of the enacted curriculum (Remillard, 2005).

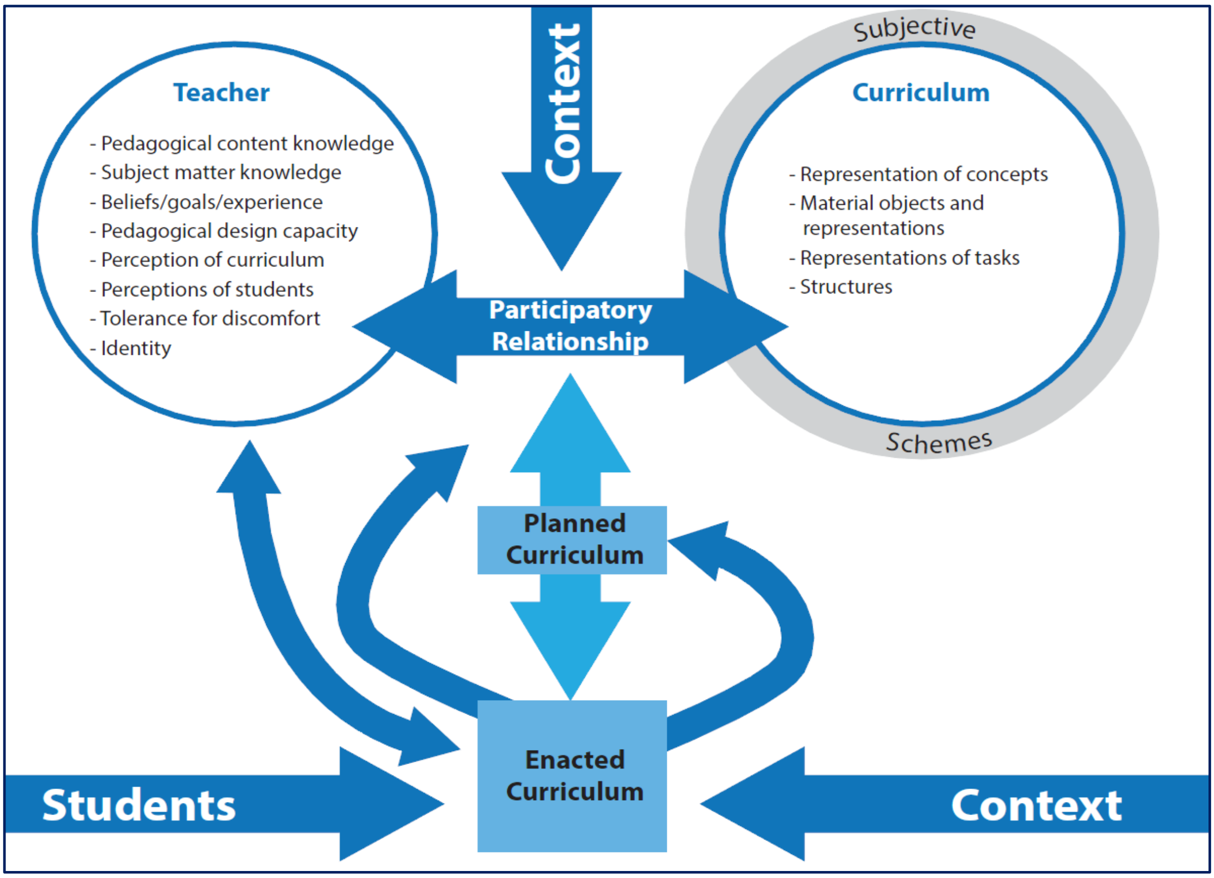


Figure 6-4 Model of the relationship between teacher and curriculum materials (Remillard, 2005)

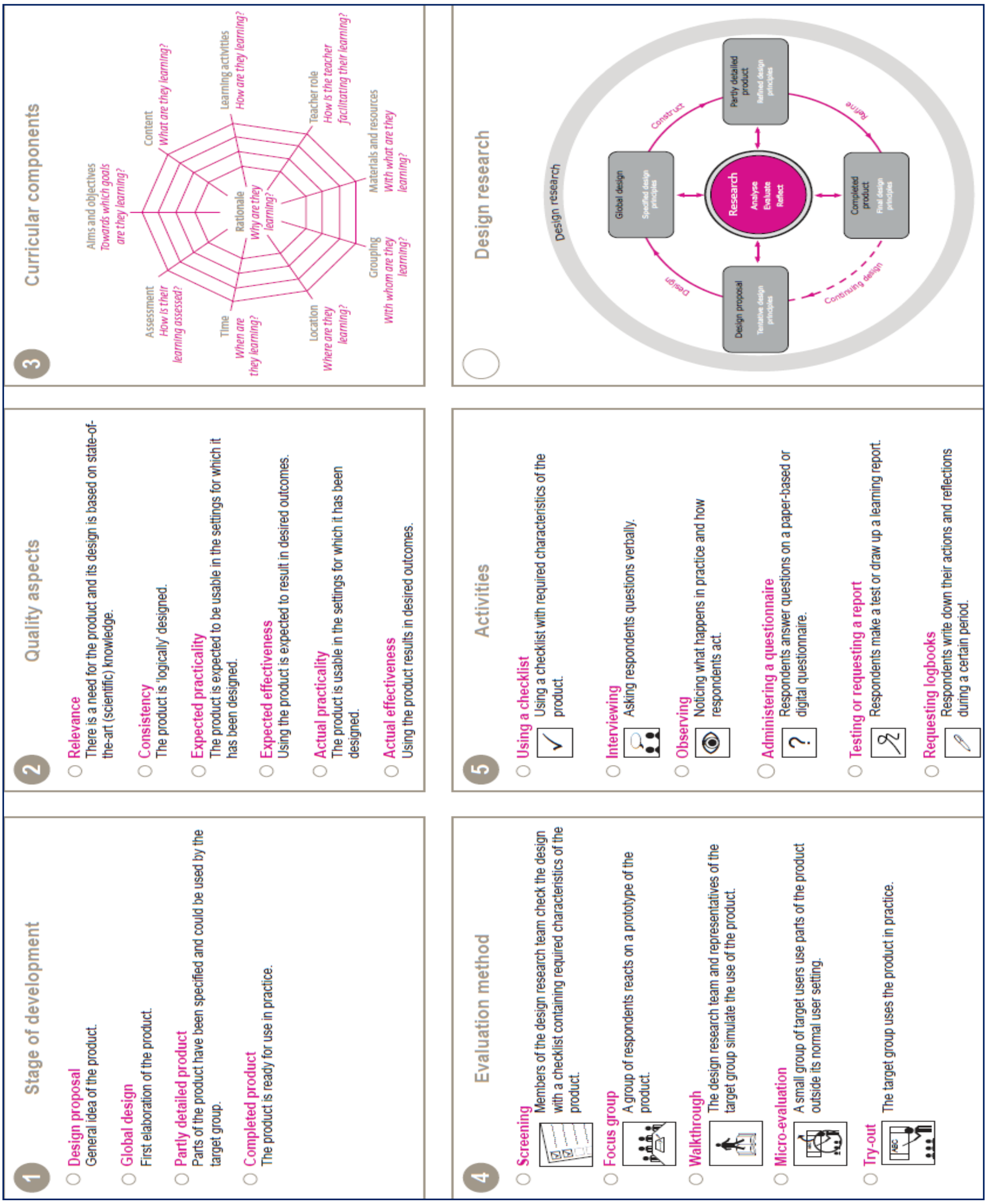


Figure 6-5 'Evaluation Matchboard' for Educational Research Design (Nieveen et al., 2012)

To support the planning of formative evaluation the Netherlands Institute for Curriculum Development (SLO) developed an Evaluation Matchboard (figure 6 - 5). (Nieveen, Folmer, & Vliegen, 2012) This evaluation tool is used for both of the projects discussed in Section 6.3.

Two design based research projects were carried out with groups of teachers and learners in classroom settings. The first project, *Asteroids, Impacts and Craters* set out to demonstrate how key skills can be embedded in learning outcomes and in doing so, to illustrate that the development of key skills, problem-solving and ,and higher order thinking skills does not have to be at the expense of acquisition of discipline knowledge. The second project explored how practical assessment, that was feasible in and Irish context could be used to support the teaching and learning of *hands on* science that was also *minds on*.

6.2 Asteroids Impacts and Craters

6.2.1 Research design

The research method employed was design based research; data was collected from teachers, students and science education experts. This methodology gave the researcher the opportunity to co-collaborate with teachers and science education researchers. In the design of the project. In this regard the researcher was able to interact with the teachers and learners at all stages of the project, including the design stage, because of this, issues and questions could be addressed as they arose in practice. This enabled the dynamic factors affecting individual classrooms to be taken into account. An added advantage of this was that the researcher was able to experience the unique culture of each school and ascertain the influence of that culture on the output.

Six schools were invited to participate in the research. Parental permission was obtained to video students in class and to use the video for research purposes. To avoid bias, and to ensure that there was fair representation of the population the sample comprised a selection of school types: rural; urban; community and comprehensive VEC; Voluntary secondary; and private. In order to reduce gender bias, the sample was composed of approximately 50% males and 50% females.

The data was collected during a six week period. Each teacher was visited twice during class time, once by the researcher and once by a participant from NCTMSTL. On one of the occasions the class was videoed, on the other, the class was observed, and observations noted.

Teachers were interviewed at the beginning and the end of the project. The teachers and students were videoed and observed during lessons. The process was made as flexible as possible in order to facilitate the busy schedule of schools, and the demands on teachers' time. The timetable for classroom observations and videotaping was structured so as to capture as much of the different teaching and learning methodologies as possible without having to artificially *create* teaching and learning environments.

Learners' behaviour was aligned to key skills development and problem solving, and sections from the videos were used to illustrate key skills in learning. The video material was used to identify student behaviour that illustrated opportunities that arose through their participation in the activities to develop key skills. The observations of the lessons were discussed and summarised by the researcher and NCEMSTL; the interviews were administered and analysed by NCEMSTL.

6.2.1.1 Data analysis and presentation

The video data was used to ascertain how the teachers and the students employed the methodologies, and how the key skills were visible in their behaviour. The interview data was analysed to determine the developing attitudes of teachers as they participated in the research. The observations were collated and fed in to the process.

The collected data was presented to the curriculum developers to feed in to the curriculum development process. It provided practical examples of how learning outcomes translated into curriculum practice. This provided information for them to take further action arising from the conclusions and recommendations from the research.

6.2.1.2 Limitations and assumption

Various assumptions are made and limitations encountered.

It is assumed that the selected sample represents the characteristic of the whole population. As the sample size is small, the conclusions and recommendations from this research can only be indicative of the whole population, however, they provide a good indication for directions of larger scale projects in the future.

The students with which this research was carried out were not studying the revised specifications, and as they were either 5th or 6th year students studying the current physics syllabus. It was important that they were prepared properly for the current Leaving Certificate which is more content focused, and less skills oriented than the revised specifications. One of the limitations was that it was not possible to use the assessments developed by teachers for the revised specifications with the students in this research project.

This project will now be discussed in terms of:

6.2.2 Aims

6.2.3 Setting up project and context

6.2.4 Activities developed and implementation

6.2.5 Results from implementation and evaluation

6.2.6 Conclusion

6.2.2 Aims

The aims of the project Asteroids Impacts and Craters were:

- To show how the development of key skills and inquiry based learning is embedded in the revised specifications for Leaving Certificate science
- To illustrate how the development of key skills, *a*nd higher order thinking skills can be integrated with and embedded in development of conceptual ideas.

Asteroids, impacts and Craters was a curriculum development research project to demonstrate how learning outcomes can translate into classroom practice in which learners develop key skills as they absorb physics concepts in an authentic context. The aim of the project was to illustrate key skills, and higher order thinking skills embedded in learning outcomes, and in addition to elucidate the evidence that would demonstrate the achievement of learning outcomes and reaching personal targets.

The European Space Education Resource Office43 ESRO and the National Centre for Excellence in Science, Mathematics and Science Education NCEMSTL participated in the project, along with six teachers and their students from six different schools. The material used for the Asteroids Impacts and Craters project was adapted from material that is freely available from ESERO. The European Space Education Resource Office in the UK (ESERO-UK) is one of the many quality educational resource banks that helps teachers use contexts to enrich the teaching and learning of science, technology, engineering and mathematics (STEM) subjects in schools.

6.2.3 Setting up project and context

The sample frame used for the research comprised educators currently involved in upper second level physics education. This included 6 teachers who are currently teaching upper second level physics, 93 students who are currently studying physics in 5th or 6th year, and 5 science education researchers. The schools invited to participate were known to be innovative and had open mind-sets, i.e. it was a convenient sample. This was considered appropriate as the focus of this research was on development and design rather than on changing attitudes.

In this project a group of teachers were asked to teach the physics topics of kinematics and energy using the context of an asteroid impacting on a planet. While the content of the learning outcomes was familiar to the teachers, the context was not.

The main reason for choosing an unfamiliar context to teach familiar content was to move the focus away from *what* was to be taught to *how* it was to be taught, and importantly how it was to be learned. There are ongoing debates about the balance between skills and knowledge; by teaching a familiar unit in an unfamiliar context, it was hoped to show that once the fundamental science was right, multiple and varied opportunities to apply fundamental physics concepts to different contexts would promote skills development as knowledge builds.

[43] http://www.nationalstemcentre.org.uk/elibrary/collection/113/esero-uk

- The context of space was chosen for this project as it is considered to be one of the areas of science that engages students at all levels. The much quoted *Apollo Effect* is an early example of the relationship between exposure to space exploration topics and attitudes to science education (Figure 6-6).

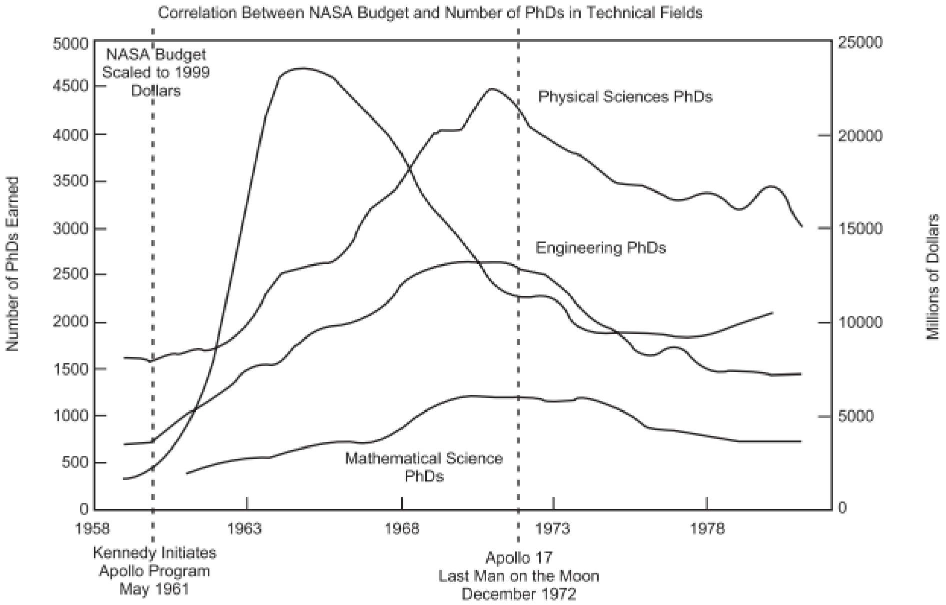


Figure 6-6 The Apollo effect (Siegfried, 1996)

- The science of space has been further popularized in recent years through television programs and popular science celebrities such as Brian Cox, an astro-physicist who presents popular television programs about the science of the universe, and Daire O'Brian, a well-known Irish comedian who hosts television programs about mathematics and science. For this reason, and because of the wealth of material available, the context of space to teach physics was chosen.
- Although space is represented in some of the learning outcomes in the LC physics syllabus, the aim of the project was not to teach about space; it was to apply fundamental physics concepts to the context of space to deepen learners' understanding of those concepts and provide opportunities for learners to collaborate and use their science knowledge and understanding to solve problems in unrehearsed contexts. In this project learners were guided to use their knowledge and understanding from the physics areas of: energy (conservation of

energy); Newton’s laws; mass; density; volume; collisions; and forces to simulate and explore the impact of an asteroid hitting a planet.

The project was part of a collaborative effort involving the researcher with other experts, teachers and students (Table 6−1)

Organisation	Role
NCCA	Research design
ESRO[44]	Space science expertise. Source of eight suggested activities from ESRO resource bank
Science Education expertise	Hosted meetings and teacher workshops, developed material Conducted interviews with teachers
6 Post Primary schools	Engaged in a /learning/ trying/ implementing/feedback cycle
6 Post primary schools	Learning through participation Presenting artefacts Subjects of video material

Table 6-1 Participants and roles in the project Asteroids Impacts and Craters

The tasks provided by ESRO were on the following topics:

- What are asteroids?
- Light curves
- ICT and simulation
- Light curves extension
- Impacts and craters

[44] Supported by Science Foundation Ireland

Following the initial input from ESRO, a group of researchers from The National Centre for Excellence in Mathematics Education (NCEMSTL) provided feedback on the initial draft of the activities, adapted from ESRO material and offered advice on the choice of the activity that was used. They were involved in the adaptation of the activity and provided science education expertise in the first stage of trial and redesign of the task. The NCEMSTL remained as part of the research team until the end of the project.

The six teachers, who were invited to participate in the project were known to be enthusiastic participants in inquiry based learning, and experienced in engaging students in collaborative group work and project work. It is noteworthy that because the participating students were all in either in 5th or 6th year of their Leaving Certificate course in physics, the project was not an add-on to normal teaching. The participating students were following the 2000 physics syllabus which has a more traditional approach to physics content than the revised syllabus. Because the learning that took place during the project would form part of their preparation for the Leaving Certificate physics examination, it was essential that students developed conceptual understanding of fundamental physics topics as well as key skills. The project timeline was developed in line with Reeves design principles (Figure 6−7)

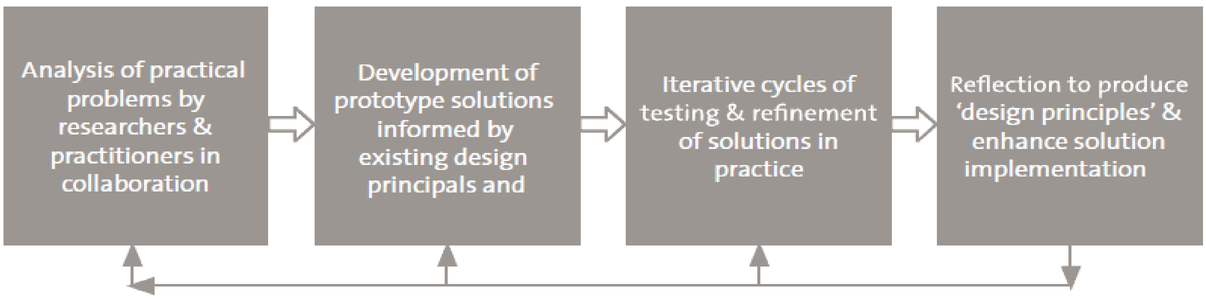


Figure 6-7 Refinement of problems, solutions, methods and design principles (Reeves, 2000, 2006)

Teachers were invited to attend a workshop to introduce them to the revised specification, and in particular make them familiar with the key skills framework, and the aim and objectives of the revised specifications. Teachers were introduced to the project and provided with an outline framework. The teachers were asked to consider how they would integrate the project material into their physics classes. It was important to give teachers time to prepare their students, as they would be using their physics understanding in applied contexts, the ground-work in the fundamental physics concepts was covered in class before the next workshop. In workshop two, teachers were provided with a selection of materials such as sand, meter sticks, candles string, etc. They were put into groups and asked to carry out an investigation on asteroids impacts and craters. In the investigation, they were asked to be mindful of ways in which each of the key skills was encountered during the process. Following this workshop, there was a six week period in which the teachers carried out the activities with their classes. During this time, each of the classes was videoed. At the end of the six weeks, teachers came together to feed back on the process, to comment on the material and contribute to the adaptation of the material.

September	• Development proposals discussed
October	• Schools invited to participate
January	• Workshop 1:Integration of key skills
February	• Workshop 2: Development of ideas
March -April	• classes visited and observed
March -April	• Teaching: Classes videoed
April	• Teachers' feedback and review
June	• Presentation to development groups

Figure 6-8 Asteroids Impacts and Craters timeline

6.2.4 Activities developed and implementation

ESRO provided a selection of learning activities that mapped well on to the Leaving Certificate physics specification. The tasks were modified and developed into a series of activities which were then used to complete a skills matrix. E.g. Table 6.2 outlines the skills matrix in terms of evidence, skills criteria and curricular links for 8 activities modified from the *Observing Asteroids and Measuring Impact Craters* material from ESRO.

Task	Evidence	Skills criteria	Curriculum links
Activity 1 **Are all asteroids in an orbit between Mars and Jupiter around the Sun?**	**Keys skills developed:** • Information Processing • Communicating • Being Personally Effective • Critical and Creative Thinking • Pupils will enhance their ability to learn and increase their capacity for learning through self-discovery and accruing of knowledge. -draw up a 'to do list' to get the idea started *Thinking, problem solving, decision making*	**Pupils will:** • Access information • Select relevant details • Analyse data • Use meaningful ICT resources • Record and organise own work • Communicate findings or conclusions • Self-manage information collection and time • -prioritise which step to take first *Self -management*	• Teacher uses query as an initial entry point to discuss Newton's Laws: • Newton's refinement of Kepler's Third Law • Force of gravity between two masses • The variation of 'g' with distance from the centre of a planet • Circular and elliptical motion

Task	Evidence	Skills criteria	Curriculum links
Activity 2 **Research these terms and discuss in the classroom. Which of the terms (periodic, aperiodic) describe asteroid light curves?**	**Keys skills developed:** • Information Processing • Communicating • Being Personally Effective • Critical and Creative Thinking Pupils will learn how to develop an understanding of science based terminology through investigation and critical thinking.	**Pupils will:** • Access information • Select relevant details • Analyse meaning • Communicate and discuss results and findings • Use meaningful ICT for research • Record and organise own work • Manage information • -prioritise which step to take first *Self –management*	Teacher sets task to investigate the use of graphs and data analysis using asteroid rotation as the key for inspiration. Task involves pupils accessing ICT and developing self-understanding of the difference between periodic and aperiodic light curves.

Activity 3	Prescribed learning outcome	Pupils will:	Equations of motion
Can the rotating potato be manipulated to emulate some of the observations and thus give the individual a better understanding of how we use this technique to observe asteroids?	Keys skills developed: • Information Processing • Working with others • Communicating • Being Personally Effective • Critical and Creative Thinking Pupils will adopt scientific and problem solving methodology to observe and manipulate information and data to communicate knowledge based response or conclusion.	• Identify controls and variables • Prioritise learning • Develop testable hypotheses • Initiate and plan all aspects of data collection and manipulation • Use problem solving techniques and evaluate findings • Communicate findings or conclusions • Use meaningful ICT for research • Develop team work skills for real life • Record and organise own work • Manage information • Develop personal capabilities • -prioritise which step to take first	Teacher uses experiment to help pupils develop an appreciation of Scientific methods of observation, investigation and data analysis Investigate how reflectivity varies with surface texture, composition Use data to investigate rotational angular momentum and discuss appropriate equations of motion. What can the data tell us about asteroid shape and structure

<table>
<tr><th>Task</th><th>Evidence</th><th>Skills criteria</th><th>Curriculum links</th></tr>
<tr><td>Activity 4

Light curve extension work</td><td>Open-Ended Investigation

Keys skills developed:
• Information Processing
• Working with others
• Communicating
• Being Personally Effective
• Critical and Creative Thinking

Learners will challenge their own observations and conclusions through project test based inquiry and develop further creative skills in data collection and analysis.</td><td>Learners will:
• Define suitable inquiry questions and criteria
• Further develop testable hypotheses
• Initiate, plan and engage in data collection and analysis: perform, record, analyse, interpret data
• Evaluate and communicate results
• Use meaningful ICT and sensor technology
• Develop team work skills
• Record and organise own work
• Manage information
• Develop personal capabilities such as problem solving</td><td>Further develop understanding of Kinematics and dynamics using scientific experimentation and sensor technology to vary parameters and test hypotheses</td></tr>
</table>

Task	Evidence	Skills criteria	Curriculum links
Activity 5 **Simulation and Using ICT**	**Prescribed learning outcome** Keys skills developed: • Information Processing • Communicating • Being Personally Effective • Critical and Creative Thinking Pupils will develop an understanding of the benefits of using models and simulation for scientific knowledge based development of testable hypotheses.	**Pupils will**: • Identify controls and variables • Collect and analyse data and evaluate findings • Communicate findings or conclusions • Use meaningful ICT and simulation for research • -prioritise which step to take first *Self -management*	Teacher uses simulation to stimulate discussion on Kinetic and Potential energy. Pupils simulate asteroid collisions with Earth and report findings/conclusions to class Use data to solve appropriate problems involving force, mass and acceleration and/or as a motivational introduction to discuss Newton's Laws Discuss Momentum Conservation Principle

Task	Evidence	Skills criteria	Curriculum links
Activity 6 **Impact craters in the lab**	**Prescribed learning outcome** Keys skills developed: • Information Processing • Working with others • Communicating • Being Personally Effective • Critical and Creative Thinking Pupils will develop project and inquiry based skills using creative skills to develop scientific knowledge	**Learners will:** • Identify controls and variables • Prioritise learning • Follow experimental procedures • Develop testable hypotheses • Initiate and plan all aspects of data collection and manipulation • Observe and measure • Collect and analyse data • Use problem solving techniques and evaluate findings • Communicate findings or conclusions • Use meaningful ICT for research • Develop team work skills for real life	Students learn about Kinematics and Dynamics by developing scientific investigation and observation skills Teacher led task: Design an experiment in the classroom to investigate the Kinetic Energy of an impacting body on various surfaces Collecting data and using graphs Demonstration of Newton's Laws

Task	Evidence	Skills criteria	Curriculum links
Activity 7 **Can I emulate a crater on The Moon or other Solar System body?**	**Open-Ended Investigation / Research Learning outcomes** Keys skills developed: • Information Processing • Working with others • Communicating • Being Personally Effective • Critical and Creative Thinking Pupils research existing data and observation relating to bodies in the Solar System to develop an understanding of real world implications.	**Learners will:** • Identify and refine good inquiry questions • Develop testable hypotheses • Initiate and plan all aspects of data collection and manipulation • Perform and record results • Analyse and interpret results and findings (also Research outcome) • Use problem solving techniques • Develop team work skills • Research: • Access existing information • Use meaningful ICT for research • Record and organise own work • Manage information	Following on from task 5, pupils research existing impact craters in the Solar System and design classroom experiment to try to emulate the observed crater Project led interrogation of Newton's Laws of motion and Kinematics to create an observed reality (Emulation of an existing impact cater to test hypotheses) Possible discussion topics: Would the result change if gravity was a higher of lower value? Do the results correlate with current theory? How do you interpret errors?

Task	Evidence	Skills criteria	Curriculum links
Activity 8 **Finding and measuring impact craters on Earth**	**Research** Keys skills developed: • Information Processing • Communicating • Being Personally Effective • Critical and Creative Thinking Learners research existing data and observation using meaningful ICT resources to develop a real world understanding of the implications of the previous learning.	**Learners will:** • Access information • Select relevant details • Analyse data for patterns and meaning • Identify bias and communicate findings or conclusions • -prioritise which step to take first • Self -management	Distance, scale and measurement Using ICT

Table 6-2 Skills matrix

In *Asteroids Impacts and Craters* the teachers worked together with the research team to develop innovative teaching and learning strategies including collaborative group work and learning through talk and discussion. Throughout the project, the teachers were supported and provided with mentoring by the research team as they used the material to develop teaching learning and assessment strategies. The focus of the teaching and learning was on skills development, both the identified key skills, and the higher order skills of critical thinking, problem solving, reasoning and evaluation. Teachers were brought on their own learning journey as part of the project, so that they could then guide their students on the same journey.

The objective of these learning journeys was to develop an understanding of physics in the Solar System using astronomy and space as the context of the learning. Learners engaged in a series of tasks relating to asteroids and impacts that reflected elements of the physics specification. They were encouraged to explore physics through scientific inquiry and investigation to develop their knowledge and understanding of nature, and of the laws of physics. The learning is mapped against critical thinking skills and the development of the five skills identified as central to teaching and learning across the curriculum at senior cycle. *Information processing, being personally effective, communicating, critical and creative thinking* and *working with others* (see Section 2.3). Building these skills into the teaching and learning is intended to broaden the learning experience and to create an individual that can become a future skilled contributor to society.

Each of the tasks in the activities were mapped to key skills, criteria for skills development and suggestions for methods of curricular engagement. The latter was merely a suggested pathway to learning outcomes within the curriculum specifications; teachers were encouraged to provide opportunities for learners to navigate their own journey through interaction, discussion, collaboration inquiry based learning. By highlighting the skills associated with learning, it was intended to demonstrate that curriculum engagement becomes a more interactive process, and allows teachers and learners to work together to create a more applicable learning solution for the Leaving Certificate sciences.

6.2.4.1 The physics behind asteroids impacts and craters

Teachers were given the task as shown in Figure 6−9

"You are a space geophysicist but the high speed launch gun you use to launch projectiles at targets is getting repaired. Is there another way for the geophysicist to launch projectiles at the targets?"

Figure 6-9 Teacher's problem

The teachers discussed the physics topics that could be covered using an investigation such as this

1. Energy – Conservation of energy (Figure 6−10)
2. Newton's 1st, 2nd and 3rd laws (Figure 6−11)
3. Mass, Density and Volume
4. Collisions
5. Gravity
6. Trigonometry

Energy

To demonstrate conservation of energy both potential energy E_p and kinetic energy E_k are required. An example of how this could be investigated is to drop a marble (Figure 6−10). Potential energy of the system can be worked out using the formula *mgh* as the mass *m*, height h, and acceleration due to gravity g are all known. As the marble is released it undergoes movement and as it impacts the sand this energy is converted in to kinetic energy with the formula $\frac{1}{2}mv^2$.

Gravity

- An experimental value for gravity could be worked out
- Gravitational forces could be incorporated into the general theme of the experiment
- What would one expect with an impact on different planetary surfaces?
- Good tool to visually describe impacts on other surfaces

Trigonometry

- Depending on mathematical background, could be introduced as a measuring technique for impact cratering
- Would require basic measurements of marble depth.
- Require diagrams and mathematical functioning
- Reinforces the math & physics aspects

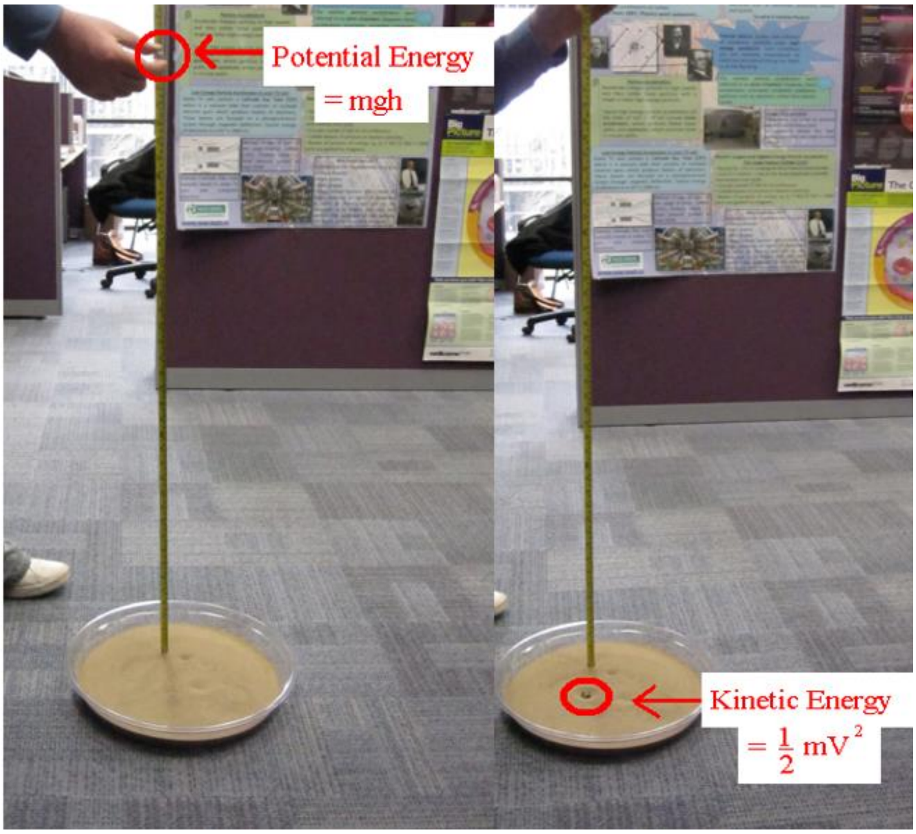


Figure 6-10 Energy

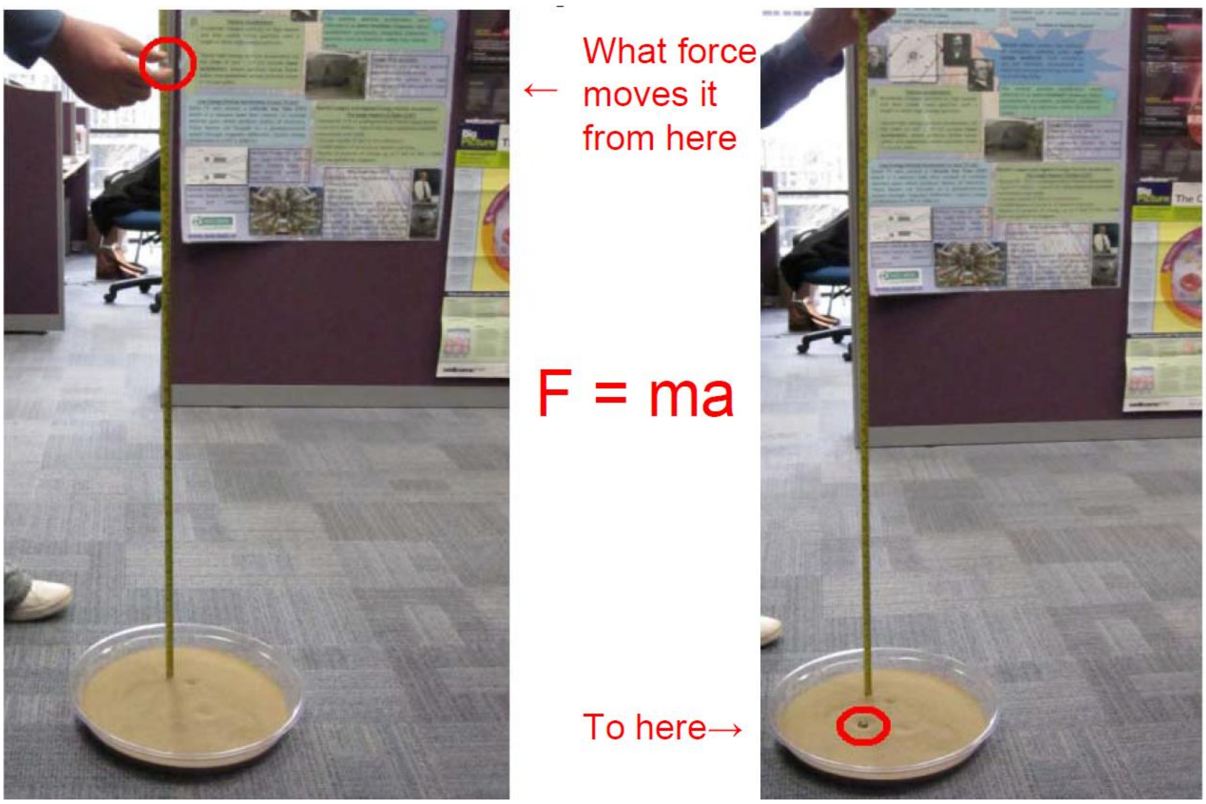


Figure 6-11 Newton's Laws

Teachers were also encouraged to use other data such as google maps.

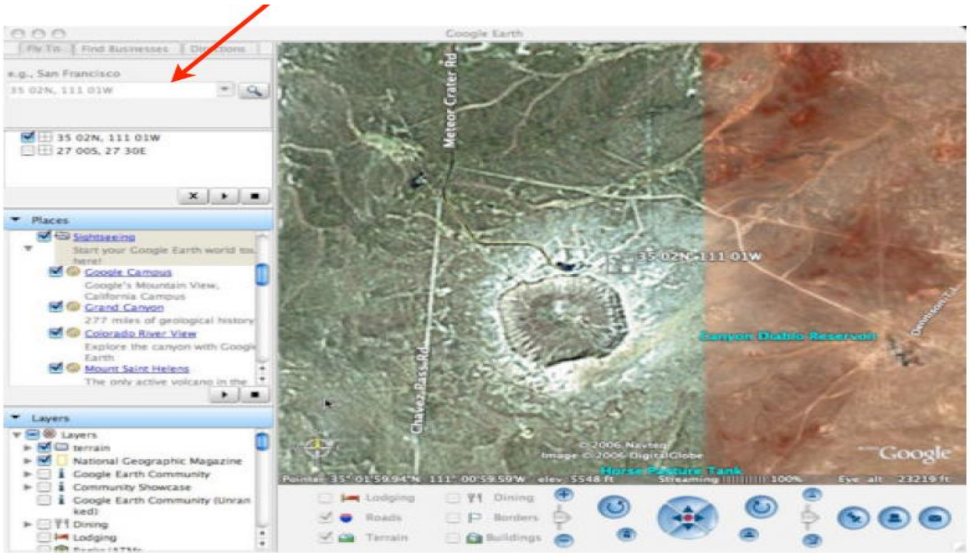


Figure 6-12 Google maps

The important things that teachers were asked to consider as they carried these out with students

- Important to identify the physics involved
- Develop a set of tasks based upon the physics
- Keep the various aspects of physics relative to one another
- Work the tasks into your timeframe
- Interesting tasks makes for interesting physics

A video presentation of the physics behind asteroids impacts and craters can be viewed by clicking on this link

6.2.5 Results from implementation and evaluation

6.2.5.1 Embedded key skills

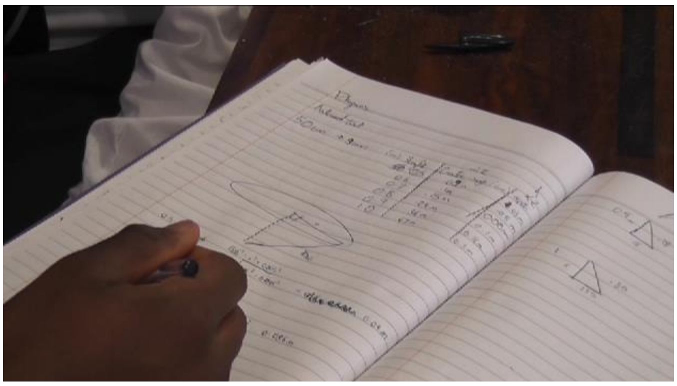
As students engaged with the fundamental principles and concepts of physics through participation in the project, they built on their knowledge of physics as they developed *information processing* (Figure 6-16) and *critical and creative thinking* (Figure 6-13) skills by examining patterns and relationships, analysing hypotheses, exploring options, solving problems, and applying those solutions to new contexts .They developed skills in *communicating* as they discussed their ideas and presented their conclusions. They developed skills in *working with others* (Figure 6-17) as they collaborate on their investigation and presented and communicated their findings. In their investigations, they solved physical problems they used careful observation, thoughtful analysis and clarity of expression to evaluate their evidence, and made a clear presentation of their proposed solution. Students researched scientific information that was current and balanced, by deciding on the validity of the research they developed a critical approach to accepted physical theories and in so doing come to understand the limitations of science. Throughout the project, the students were asked to monitor and evaluate their learning and in doing so, developed the skill of being *personally effective* (Figure 6-15)

Critical and creative thinking

Making a mould to find the volume of the 'crater'

The students devised creative ways to measure and collect data

These students used wax moulds to measure the volume of their craters.

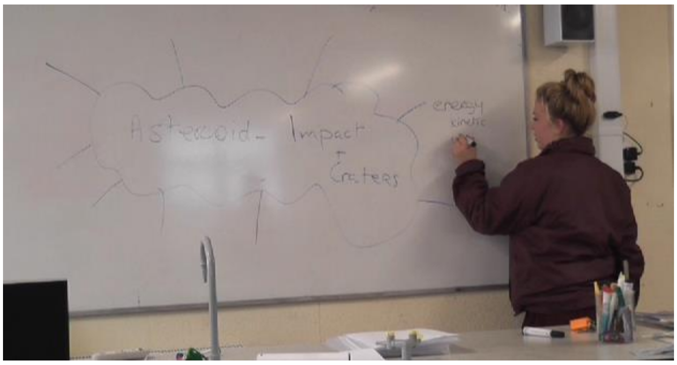


Using trigonometyry to find the volume of the crater

These students also wanted to measure the size of their craters, but they used trigonometry. They found the depth and the length of one side of the triangle formed by the impact with a damp splint.

Figure 6-13 Critical and creative thinking

Communicating

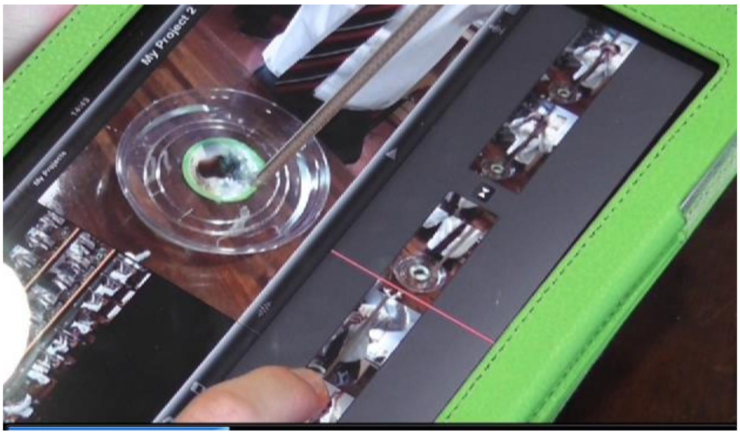


Presenting their results

This group of students discussed their ideas with the rest of the class before embarking on their projects. Each group got feedback from the rest of the class and redesigned their investigations based on that feedback.

Figure 6-14 Communicating

Being personally effective

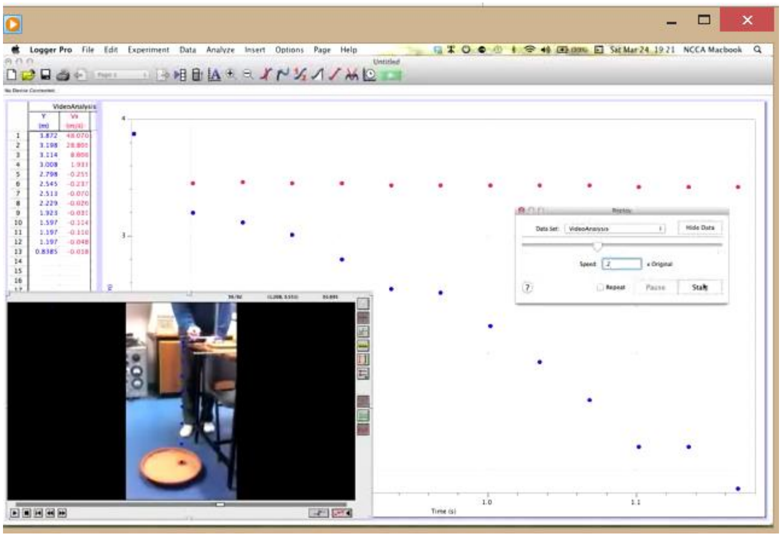


Devising a way to measure shock-waves

These students filmed the ripples caused by the impact. They used slow motion film to measure the speed of the waves. They decided on this strategy after a group discussion about the shock-waves that would be caused by an impact.

Figure 6-15 Being personally effective

Information processing



Students used ICT to analyse their results.

Figure 6-16 Information processing

Working with others

Each person in the group had their own roles. The students worked together to research, plan, devise, and evaluate the investigations. They then worked together on a presentation which they presented to the group at the end of the six weeks.

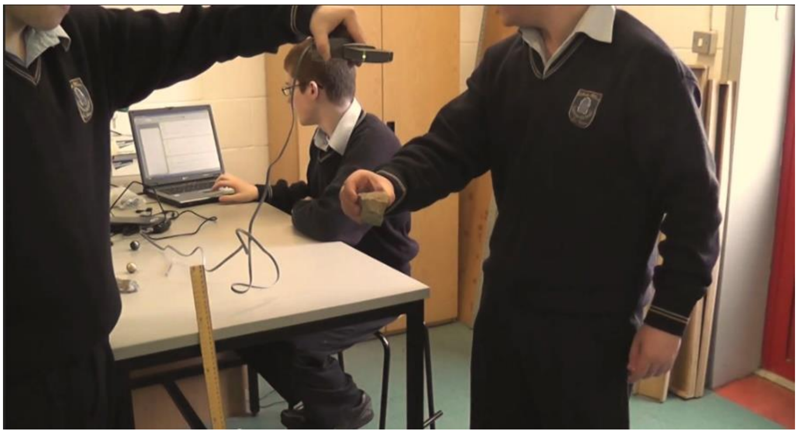


Figure 6-17 Working with others

6.2.5.2 Educative curriculum materials

Part of the work with schools was to investigate the kinds of support materials that teachers would find useful in helping them to interpret learning outcomes. Curriculum materials intended to promote teacher learning in addition to student learning, are referred to as educative curriculum materials (Davis & Krajcik, 2005) (Ball & Cohen, 1996). Educative curriculum materials help teachers increase their pedagogic content knowledge (PCK), and educate them in how to apply that learning to new situations (Davis & Krajcik, 2005). Educative curriculum materials that emerge from research and practice are needed in addition to, and not instead of text-books. Text-books have a particular role in curriculum, and will probably always have a place as a student resource, but in the absence of other sources, teachers come to rely on textbooks for methodology as well as content. According to some researchers, content is not always produced in a way that is *pedagogically sound* (Davis & Krajcik, 2005), or it is offered with an over-emphasis on factual knowledge and not on students' understanding about the processes of science (Galvão 2014). In addition to this, there is a danger that when a curriculum changes, particularly in terms of pedagogy, that text book authors may rely on traditional methods of presenting new content, as indicated in a recent review of text-books for project maths (Keeffe & Donoghue, 2011). In this review, Keefe and Donoghue highlighted that:

- All textbooks included in the study fall short of the standard needed to support Project Maths (intended curriculum) effectively
- These textbooks display a genuine attempt to match the intentions of Project Maths but no one textbook meets all the needs of Project Maths
- The most significant overall finding is the mismatch between textbook expectations and Project Maths expectations
- It is noteworthy that there are topic omissions in the reviewed textbooks when the Project Maths syllabus treats all topics as compulsory
- A key topic omission is the integration of ICT throughout all textbooks
- Structure and content analysis uncovers disparities between the textbooks in their approaches to teaching for understanding and problem solving.

Throughout the consultation and the discussions by the curriculum development groups, reference has been made to the importance of quality educative curriculum materials that go beyond listing curriculum with contexts for teaching and clear illustration of pedagogy and guidance on how change can happen in the classroom and on ways to evaluate the extent to which students have achieved learning outcomes.

One of the outputs of Asteroids Impacts and Craters was a set of educative curriculum materials to use with participating teachers. The need for educative support materials stems from the nature of the learning outcomes, and while there are a variety of ways to reach a learning outcomes, support for teachers in guiding students to the learning outcomes is more important that showing them *how* and *what* to teach.

Davis and Krajcic designed a set of useful heuristics for educative curriculum material built around teacher's subject matter knowledge, pedagogical content knowledge for topics, and pedagogical content knowledge for disciplinary practices (Krajcik, 2005) see column 1 in Table 6−4. The educative curriculum material that was produced for *Asteroids Impacts and Craters* is categorised according to Davis and Krajcic and shown in column 2.

Design heuristics for PCK: supporting teachers in:	Asteroids impacts and craters educative curriculum material
engaging students with topic specific phenomena	The materials make the physics topics outlined above accessible to students, and include pedagogical rationale. The materials provided suggestions and help for teachers to think about sequences for experiences, rather than provide a lesson plan.
using scientific instructional representations	The material provided support for teaches in adapting and using appropriate analogies and models. The potential limitations of the models were highlighted, and used to provide stimulus for scientific discussion. Explanations were given about how and why a particular representation was scientifically and pedagogically appropriate.
anticipating, understanding and dealing with students ideas about science	The material was designed to help teachers to recognise the importance of students' own ideas, and to support them to gain insight into possible student ideas related to a topic. There were suggestions of ways to promote the development of further ideas.
engaging students in questions	The material provided stimulus questions and focus questions to help to lead and develop the subject area. There were rationales as to why particular questions are scientifically and pedagogically productive.
engaging students with collecting and analysing data	The materials provided teachers with approaches to help students to collect compile and understand data, and to understand why evidence, and argumentation based on evidence is so important in scientific inquiry.
engaging students in designing investigations	The materials provided guidance to teachers for to support students design their own investigations, including appropriate design suggestions and ways in which to support students to improve on their designs.
engaging students in making explanations based on evidence	Materials show teachers how to help students to make sense of data and generate evidence based on data. This includes rationales for why engaging students in explanations is important in scientific inquiry, and why particular approaches for doing so are scientifically and pedagogically appropriate.
promoting scientific communication	The materials show teachers how to promote scientific communication both amongst themselves and in the generation of artefacts, and provide scientific and pedagogical justification for particular methods of communication.
the development of subject matter knowledge	The material supports teachers in developing factual and conceptual knowledge of science content, including concepts likely to be misunderstood by students. The material helps teachers see how scientific concepts relate to real work phenomena.

Table 6-3 Educative curriculum materials

The quality aspects and the evaluation method of *Asteroids Impacts and Craters* are shown in Table 6–4.

Quality aspects	
Relevance	There was a need for teachers, and curriculum developers to see examples in live situations of how key skills could be embedded in teaching and learning, while at the same time aiming to promote deeper learning of scientific knowledge and understanding through engagement, discussion, problem solving and inquiry.
Consistency	The product was designed according to a skills matrix. The design started from the point of what the learners should be able to do having completed the course; teaching and learning activities were developed to enable learners to reach these goals.
Expected Practicality	The product was practical and designed for use in a school laboratory. Teachers engaged in the project for six weeks, the student activity was designed to span two weeks.
Expected Effectiveness	The learners achieved the expected learning outcomes. There were many exemplars of student work, and videos of classroom practice indicating the level of engagement of learners, their questions, and their active participation in learning. These products were used to inform the discussions on the nature of the learning outcomes in the LC science specifications.
Actual Practicality	The product was usable in the settings it was intended for
Actual effectiveness	Using the product resulted in the desired outcomes.

Evaluation methods	
Screening	ESRO provide expert screening of the proposed material to assess its suitability and subject matter integrity.
Focus group (expert appraisal)	Following a prototype of the product, a small group of science education experts tried out the proposed product.
Walkthrough	the design research team and representatives of the target group simulate the use of the product
Try out	The target group of teachers carried out the activity with a group of either 5th or 6th year students.

Table 6-4 Evaluation matchboard for Asteroids Impacts and Craters

6.2.6 Conclusions

The project was successful in illustrating key skills embedded in teaching and learning. Teachers were asked to plan for key skills development as they carried out the project with their students. In the initial discussions teachers were sceptical about how skills development could be done in a way that wasn't contrived or artificial; they felt that it was important not to teach skills in isolation. The practical work-shop where teachers had to carry out the investigations themselves was very useful in helping teachers to see how they could support their students' skills development, whilst at the same time ensuring that students gained a deep knowledge of the physics concepts. Teachers were surprised at the level of discussion about the physics of the investigations, and the level of productive argument that took place amongst themselves during the workshop. Teachers saw how applying physics understanding to a previously unseen context was useful in developing higher order thinking skills. The teachers planned really innovative and enjoyable lessons. It was very refreshing to see so many different investigations arising out of one set of stimulus material. The classrooms were noisy and students were all engaged. The teachers were particularly good at not giving answers; they led students to answers, or helped them devise strategies to overcome problems.

The original aim was to develop material to support the development of the specifications; however, very useful material was gained about the type of curriculum support material that will help teachers to interpret the learning outcomes. For example, teachers wanted more *open* stimulus questions that they could pose to the class to get them thinking. They said that it would be very useful to have a bank of ideas of every-day applications of the various science topics. Although this project was deliberately open, and the *Asteroids Impacts and Craters* concept could be used with any number of physics concepts, the teachers in this project suggested that in the curriculum support material there should be some examples that were linked directly to learning outcomes. These, they said, was not necessarily to be used as lessons, but they would help teachers get used to thinking about physics linked to contexts that could be usefully used in the classroom.

6.3 Project 2. Assessment of practical science

As part of the review of sciences, the NCCA were asked to develop advice on the implementation of practical assessment. The practical assessment project was a curriculum development research project to develop and try out examples of practical assessment to show what could work within the Irish education system, and so feed into the curriculum development in the area of assessment. The project also set out to illustrate how appropriate assessment could potentially impact on teaching and learning in the laboratory.

6.3.1 Aim of project

The aim of the assessment of practical science project was to:

identify the logistical problems associated with practical science and develop solutions through practice.

develop with teachers a variety of different types of practical assessment.

produce of a number of video recordings of students carrying out the task under examination conditions to provide, teachers, learners and the wider public a snapshot of what second component assessment might look like, and inform the debate on the inclusion of a practical element in assessment in Leaving Certificate science.

6.3.2 Research design

This project was a design based research project; data was collected from teachers, and students. This methodology gave the researcher the opportunity to co-collaborate with teachers and science education researchers. In the design of the project. The unique circumstances of each school was factored into the design of the project, and the logistics of running a practical examination that required use of laboratories, and use of teachers during term time was built in to the design.

Sampling and sample size

The sample frame used for the research comprised educators currently involved in upper second level physics, chemistry and biology education. This included 23 teachers who are currently teaching upper second level science, and 217 students who are currently studying physics, chemistry or biology in 5th or 6th year. Every second level school in Ireland (approximately 700) was invited to participate.213 schools responded indicating that they wished to be included in the project. The schools were divided into the different school types, Gaelscoileanna, rural; urban; community and comprehensive; VEC; Voluntary secondary; and private. Schools were selected at random from each section. The total number of schools selected was 12. In order to reduce gender bias, care was taken to ensure that there were equal numbers of boys schools and girls schools as well as mixed schools.

The schools were contacted and asked to nominate teachers to participate in the project. Each school was asked to participate in the three science subjects. Following nomination of the teachers, parental permission was obtained to video students in class and to use the video for research purposes. The process was made as flexible as possible in order to facilitate the busy schedule of schools, and the demands on teachers' time. The timetable for videoing the assessments and the interviews with teachers and students was carefully organised so that there would be minimum disruption.

The data was collected during a seven-month period between September 2009 and March 2010. Each teacher attended three workshops, and the assessments were videoed as the students carried it out.

The research employed different research tools in order to collect the most relevant data.

Teachers and students were interviewed following the assessments. The students were videoed and observed during the assessments. These two tools were very important in the research as they helped the researcher to capture the views of teachers and learners and present a view of the feasibility of an authentic assessment of practical science.

6.3.2.1 Data analysis and presentation

The video data was interrogated to ascertain how the students managed the assessment, and how they reacted to the stress of the situation. The student interview data was indicative of the attitudes of students to existence of a second component of assessment, such as the one they had just experienced. The teachers' views about the on the model of assessment, and how accurately it could be used to measure student performance were recorded.

The data and conclusions from the project were presented to the curriculum development groups. The data and the views of the learners and the teachers, as well as the live examples from Irish classrooms of models of practical assessment informed their choice concerning the model of practical assessment to propose for Leaving Certificate science.

6.3.3 Limitations and assumptions

Various assumptions are made and limitations encountered.

It is assumed that the selected sample represents the characteristic of the whole population. As the sample size is small, the conclusions and recommendations from this research can only be indicative of the whole population, however, they provide a good indication for directions of larger scale projects in the future.

The students who participated were not studying the revised specifications, and as they were either 5^{th} or 6^{th} year students studying the current physics, chemistry or biology syllabus. Students are not prepared for a practical assessment in the current science courses, so this was very new to them.

This project is now discussed under the following headings:

6.4.2 Role for practical assessment in science

6.4.3 Models of practical assessment

6.4.4 Project setup and timeline

6.4.5 Development of practical assessment items

6.4.6 Implementation and evaluation

6.4.7 Key concerns raised

6.4.8 Conclusions

6.3.4 Role for practical assessment in science

In a high stakes examination such as the Leaving Certificate, the benefits of a second component assessment in terms of the extra information it may provide, and the positive influence it may exert on teaching and learning needs to be balanced against the extra cost and complexity inherent in an external assessment of performance. Practical work is an essential part of science learning, and practical activities are an essential component of science curricula; learners will spend a significant proportion of class time engaged in a wide variety of practical activities, including open-ended inquiry. Whilst much of the substantive and procedural knowledge associated with inquiry will continue to be assessed in the written paper, it is appropriate to assess the skills associated with the collection, interpretation and validation of evidence in a practical setting by means of a performance assessment.

Learners develop skills and improve their understanding of scientific ideas and explanations over a sequence of events rather than in single activities. As practical activities become less prescriptive and more focused on skills development, they become more difficult, but more important to assess. It is far easier to assess a learner's ability to recall experimental procedure than to assess the learning that develops as they progress through a sequence of activities. In developing proposals for external, summative assessment of practical work, these difficulties and the limitations of what is possible in the Irish system was acknowledged by the curriculum developers. Assessment of performance is expensive, but its inclusion was considered essential to ensure alignment of teaching and learning with the aim and objectives of the specification.

To believe that a perfect solution for practical assessment of Leaving Certificate science subjects in Ireland exists would be naive. Discussions about practical assessment over the years have been extensive, and have featured a wide range of perspectives and understandings. What has become evident is that even the term *practical assessment* gives rise to multiple and sometime conflicting interpretations. These conflicting interpretations are as much to do with the content to be assessed as to the form that this assessment takes.

It is pertinent at this stage to evaluate the *what* and the *how* of practical assessment. One of the significant differences between the revised science specifications and previous ones is that the process and procedures of science are decoupled from specific instances. In other words scientific practices are not learned through specific experiments; students develop good scientific practices as they engage in a variety of practical activities throughout the period of their study. Each of the specifications has an overarching unit entitled *Scientific Practices* in which learning outcomes are grouped under: hypothesising, experimenting, evaluating evidence, and communicating. The application of scientific understanding, scientific process skills and societal aspects of scientific evidence exist throughout the specification.

The objectives of the revised specifications include the development of skills in laboratory procedures and techniques, the ability to assess the uses and limitations of these procedures through engagement in a wide variety of practical work and the development of investigative skills. The assessment criteria for practical science are stated in the specification, and are the same for each of the subjects.

A high level of achievement in this component is characterised by demonstration of a comprehensive range of manipulative techniques in experimental activities. Candidates make and record observations and measurements with a high level of accuracy and precision. In almost all cases candidates recognise and describe trends and patterns in data and use chemistry knowledge and understanding to account for inconsistencies and anomalies. Candidates accurately interpret and analyse experimentally derived data; manipulation of the data is almost flawless. In all cases candidates link theoretical concepts to interpretation of experimental evidence. (Draft revised physics, chemistry and biology specifications)

It is useful, in the context of the curriculum framework outlined in chapter 4 to place procedural knowledge in a simplified taxonomy (Figure 6-18) (Richard Gott & Duggan, 2002).

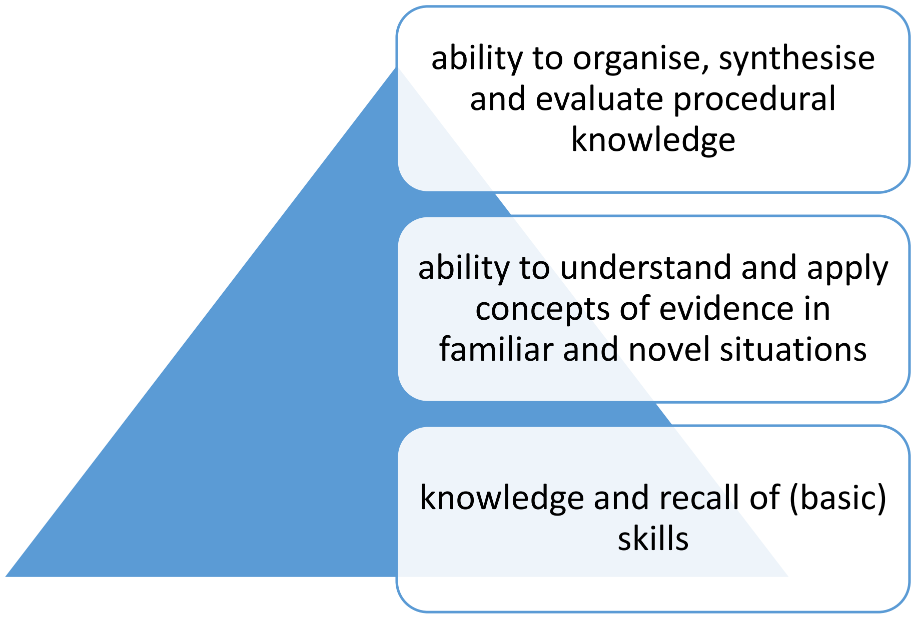


Figure 6-18 Taxonomy of procedural knowledge (Gott & Duggan, 2002)

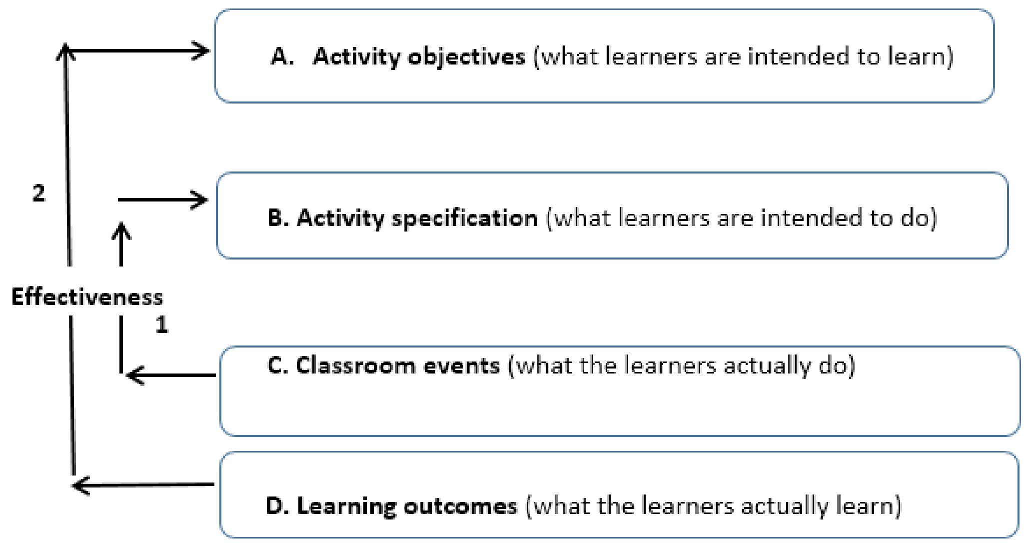
While the written assessment can assess this knowledge to some extent, the practical assessment adds the element of performance, making the assessment more authentic.

The literature refers to two domains of knowledge in practical science, the domain of objects and observables, and the domain of ideas (Tiberghien, 2000)(R. Millar, Le Maréchal, & Tiberghien, 1999) (I. Abrahams & Millar, 2008)(Reiss et al., 2012). In the context of practical work, there is a substantial difference in cognitive demand between tasks in which the primary aim is for students to observe and record a phenomenon or manipulate a piece of equipment (objects and observables), and tasks where the primary aim is for students to use their understanding of the theoretical models that account for what they observe (ideas).

Within the current science syllabuses, practical tasks are intended to support the teaching of substantive science content by providing experimental evidence to support the theory – the *doing* supports the *learning* in the domain of objects and observables. Students learn a theory and carry out a practical activity to generate data that fit with accepted scientific knowledge. The practical activities in the revised syllabus are designed to extend beyond this, students work together raising questions, and interrogating data; activities link the real world of objects, materials and events, and the abstract world of scientific thought and ideas.

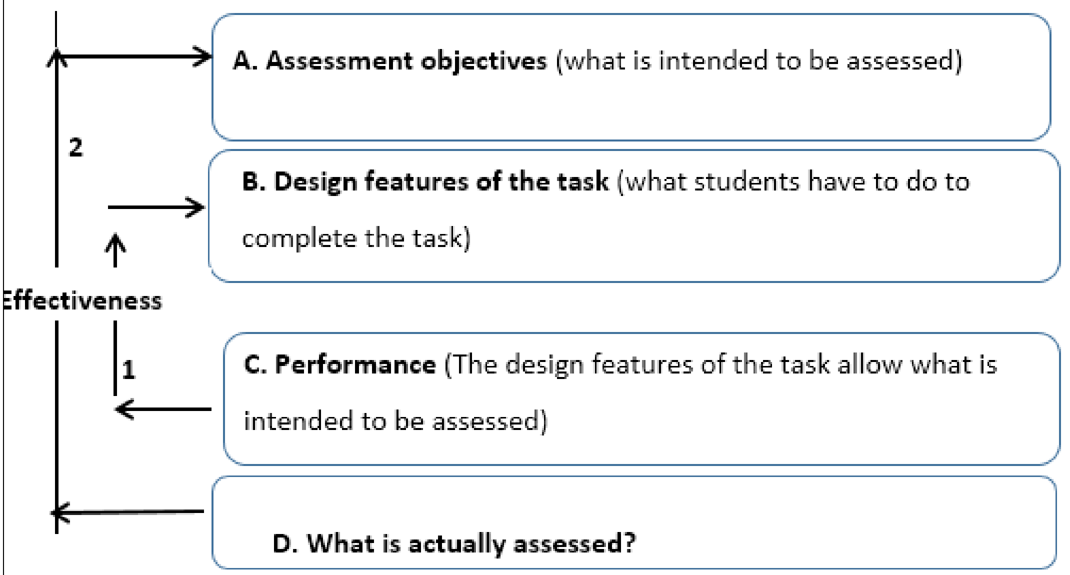
The model of the processes involved in designing practical activities, originally developed by Miller et al (1999), provides a framework for considering the effectiveness of a particular practical activity, relative to the aims and intentions of the developer (Figure 6−19). The learning intention is the starting point of the development rather than the task. A particular task is effective in senses 1 if what the learners actually do are linked to what learners are intended to do; it is effective in sense 2 if what the learners actually learn is linked to what learners are intended to learn

If a similar model is applied for the design of practical assessment tasks, (Figure 6−20), it is reasonable to expect that practical science assessment will have a positive back-wash effect on teaching and learning. In such a scenario, the assessment objective is the starting point of the development rather than the task. Just as in the model proposed by Millar et al., the learning intention is the starting point rather than the task. By using these two alternatives of Millar's model of effectiveness, it may be possible to avoid the inevitable situation where assessment is the target of learning.



A practical activity is:	in the domain of objects and observables	in the domain of ideas
effective in sense 1 if	Students do what was intended with the objects and materials provided, and observe what they were meant to observe	During the activity, students think about what they are doing and observing, using the ideas intended, or implicit in the activity
effective in sense 2 if	Students can later recall and describe what they did in the activity and what they observed	Students can later discuss the activity using the ideas it was aiming to develop or which were implicit in it and can show understanding of these ideas in other contexts

Figure 6-19 The effectiveness of practical teaching/learning activities (Millar, 2009)



A practical assessment is:	in the domain of objects and observables	in the domain of ideas
effective in sense 1 if	The doing is what was intended	If the task measures the desired conceptual and procedural knowledge
effective in sense 2 if	If the performance matches the assessment	The intended conceptual and procedural knowledge is validly measured by the task

Figure 6-20 Effectiveness of practical assessment activities (adapted from Millar 2009)

6.3.5 Models of practical assessment

There are many options available for the assessment of practical work. The choices that can be made depend on many factors. The decision was made at an early stage of the curriculum development process that the practical assessment was to be a *once off*, summative, externally assessed practical examination. For this reason, this project was restricted to formats that would satisfy these constraints.

The options that had been considered by the curriculum developers were critiqued by the project participants. Summaries of the main points of the discussions around the options for assessment are outlined in Table 6−5.

1. Inspection and assignment of marks to the laboratory notebooks		
Outline	**What is assessed**	**How it is marked**
• Students are marked on the contents of their laboratory note-book. • Students are interviewed by an external examiner. • Marks are awarded based on the interview on the laboratory note book.	• The external examiner marks the reports on the mandatory experiments. • The students' understanding of the mandatory activities is assessed by interview.	• The external examiner awards marks following examination of the laboratory note-book and interview of the student.
2. Presentation of a portfolio of practical work		
Outline	**What is assessed**	**How it is marked**
• Students submit pro-forma reports on a number of mandatory practical activities specified by the SEC. • Students submit pro-forma reports on a further two prescribed activities set by SEC.	• Knowledge and understanding of mandatory practical activities. • Reporting skills. • Interpretation and analysis of data. • Science process skills.	• The pro-forma reports on the designated practical activities and investigations are externally assessed by the SEC
3. Practical examination of one of the specified activities		
Outline	**What is assessed**	**How it is marked**
• Students carry out one of the specified practical activities specified by the SEC on a particular day. • The report on the practical activity is written on a pro-forma document and submitted to SEC for marking.	• Knowledge and understanding of the mandatory practical activities. • Reporting skills • Interpretation and analysis of data.	• The report on the designated practical activities is externally examined by the SEC.

4. Oral and practical examination of each candidate individually (based on the 1997 feasibility study)		
Outline	**What is assessed**	**How it is marked**
• Each student is interviewed for 15 minutes on their own by an external examiner. • Marks are awarded based on the student's knowledge of the contents of his/her laboratory note-book. • The student performs 4/5 practical tasks observed by the examiner who awards marks for these based on the student's performance.	• Knowledge and understanding of the mandatory practical activities. • Reporting skills, psychomotor skills, interpretation and analysis of data. • Skills of observation, measurement, deduction, conclusion and evaluation. • Appreciation of safety, application of ideas • Communication skills.	The visiting examiner awards marks for: • the completion of the mandatory activities (awarded on a pro-rata basis) • the interview based on the laboratory note-book • the 4/5 practical tasks
5. Practical examination		
Outline	**What is assessed**	**How it is marked**
• A group of students work individually to complete 4/5 practical tasks. • The student completes a paper and pencil exercise for each task on a pro-forma document. • The pro-forma is handed up on the day to be externally examined by the SEC.	• Reporting skills. • Interpretation and analysis of data. • Skills of observation, measurement, deduction, conclusion and evaluation.	• The pro-forma document is externally marked by the SEC.

Table 6-5 Options considered for practical assessment

6.3.6 Project setup and timeline

This was a collaborative project with external input involving 26 teachers from 12 schools (Table 6.6). It ran with teachers during the 2009-2010 school year. Teachers were not self-selected. An invitation was sent to every post-primary school in Ireland inviting them to participate in the project. 320 schools replied, indicating that they would like to be involved. The principles volunteered the teachers, so it could not be assumed that all the teachers were willing participants. Twelve Schools were chosen to ensure a spread of school types and geographical location, and a spread of subjects.

The project ran in three phases:

phase 1: planning

phase 2: development

phase 3: implementation and evaluation. (Figure 6.21)

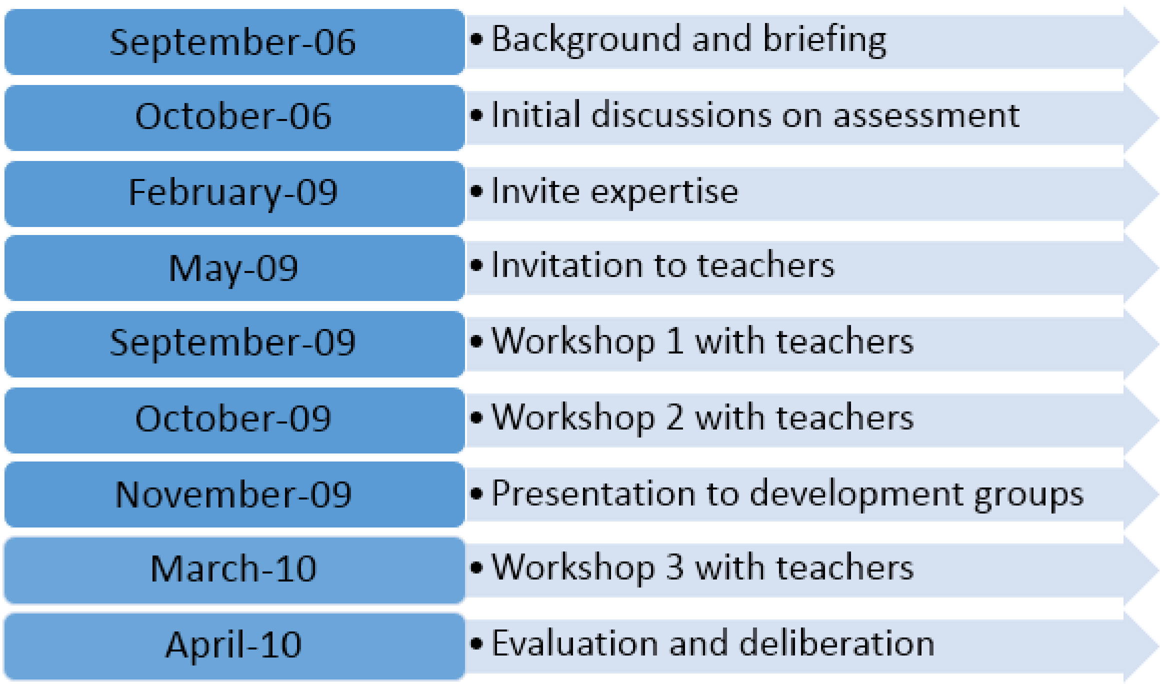


Figure 6-21 Practical assessment project timeline

Organisation	Role
NCCA	Research design
University of Durham	Practical science assessment expertise (initial and interim advice)
12 Post primary schools (teachers)	Practical task development, assessment development, reflection.
12 Post primary schools (students)	• Participation in the assessment • Reflection • Subjects of video material

Table 6-6 Science assessment project participants and roles

The project did not attempt to trial different types of practical assessments; students had not studied the revised syllabuses. Students involved were from different stages of upper second level science courses in physics, biology and chemistry, and so had varying levels of science content knowledge. For this reason, the level of the science content in the examples varies, and was not presented as, or intended to be, sample Leaving Certificate assessment material. There were three phases to the project.

- The practical tasks were developed by teachers as classroom activities, the tasks were tested in the classroom
- The teachers developed a checklist for the tasks. This was a tool to generate thinking
- A matrix was developed to audit the tasks.

Phase 1 - planning

The first phase of the projects was a planning and thinking phase; it started with a workshop that brought the teachers together to discuss the nature of the revised specifications, and how they might be assessed. Following the workshop, teachers were asked to develop a task, and plan for how they might assess that *new* learning. As support for this, teachers had access to a variety of sample practical assessment items from other countries. The number and variety gave teachers a broad view of practical assessment and the skills and processes that are generally measured internationally. During the planning phase, teachers were encouraged to conduct practical classes with their students in a way that they would like the revised assessment to drive teaching and learning. This reflective practice gave teachers an opportunity to consider the kinds of performances that could and should be assessed, based on these *live* examples.

Phase 2 - development

The second phase of the initiative was to produce the example assessment material. Each of the schools was visited and it was during these visits that the examples really began to take shape. As well as their insights into what might or might not work as assessment items, teachers brought with them their day to day experience of real students in Irish classrooms. They were able to focus on what would work best for their students whilst also keeping in mind the challenges of assessment of practical science. Teachers were brought together for a second full day workshop in which the focus was on task development. Teachers developed and agreed a checklist of criteria to help them in keeping on task. Some of the learning outcomes associated with science process can only be adequately assessed in a practical examination because they rely on demonstration of skills associated with manipulation of apparatus, collection of data and reaction to emergent data. Teachers developed examples of tasks that required students to *think* as well as *do* and to generate rather than recall answers.

The examples included variations of the following:

- One long task
- A number of short tasks
- Questions answered on a task sheet
- Questions answered as part of an oral examination
- Tasks carried out in groups
- Tasks carried out singly

The teachers agreed a checklist of criteria for the development of the tasks

Phase 3 - implementation and evaluation

The third phase of the projects took place in schools. Students were recorded carrying out the example assessments following which, they were asked for feedback on what they thought of the assessment and what they thought about having a similar type of assessment as part of the Leaving Certificate examination. The teachers who worked on the project were also asked what they thought of the assessment examples and what they felt that a second component assessment could add to the existing assessment arrangements in Leaving Certificate science.

6.3.7 Development of practical assessment items

During phase 2 of the study, teachers developed a checklist of criteria by which to critique each task. The practical skills checklist (Table 6−8) was expanded into an assessment audit tool (Table 6−9). In the final phase, the tasks were coded according to these categories using the assessment audit tool (Table 6−10).

Checklist	Yes	No
Does the task centre on an important concept, skill or principle in science		
Is the task aligned with the specification using meaningful, interesting and authentic context??		
Is the task fair and equitable to all students		
Does the task require students to use and apply science reasoning skills rather than just recall information		
Has the task got the potential to generate interest & stimulate to inquirer		
Is the language appropriate for all students		
Is the task challenging enough for exceptional students		
Does the task assess science content and skills rather than reading ability		
Is the reporting method appropriate to the task		
Is there a balance between the process knowledge and the content knowledge		
Is it a task that will drive teaching and learning		

Table 6-7 Task evaluation checklist.

Teachers were asked to evaluate their tasks based on a number of criteria (table 6–7). Following this, the teachers designed the final assessments and developed a practical skills checklist for the tasks (table 6.8). In this way, they could check the balance and spread of practical skills across the assessment items. Obviously it is not possible for every task to test each practical skill listed in table 6.8, however the checklist provided a way of monitoring the distribution of skills across tasks.

Quality of observations/data	
Appropriate readings and observations taken	
Consistent data	
Accurate measurements/observations	
Completed data table	
Correct units	
Qualitative description	
Error- recognise limits of measurement – accuracy	
Read, interpret and draw inference from tables	
Comment on any discrepancies in observations	
Proposals for any measures to help improve the reliability of data	
Scientific process	
Use scientific knowledge and understanding to justify readings taken	
Identify appropriate variable	
Predict an outcome	
Graph	
Curve is appropriate to data trend	
Points plotted accurately	
Appropriate scale	
Axes labelled with variables; Variables placed on correct axes	
Identify and explain patterns within data	
Correct values read and recorded from graph	
Draw and interpret related graphs	

Calculations	
Calculated correctly	
Substituted correctly into relationship	
Relationship stated or implied	
Units used correctly	
Use all data available	
Conclusion	
Consistent with scientific principle	
Sources of error	
Consistent with data	
Comment on discrepancies between the expected results and the experimental outcome	
Relationship among variables stated	
Variables stated in conclusion	
Account for anomalous data	
Relate scientific explanation to experimental evidence	
Explain conclusions using scientific knowledge and understanding	
Evaluate how strongly evidence supports conclusions	
Offer explanations consistent with the evidence	
Use of equipment / safety	
Safe use of equipment	
Tidy, efficient working	

Table 6-8 Practical skills checklist

Analysis				
A1	**Plot graphs**	plot 2 variables points plotted correctly	labels and units are correct;	uses all available data
A2	**Interpret/comment on results/findings**	make some connections with theory	order of magnitude	
A3	**Calculate from graph**	find slope / intercept / area	use the slope correctly	
A4	**Identify trends**	understand linear and non-linear relationships	line of best fit	curve appropriate to data trend
A5	**Interpret graphs**	identify shape explain shape	compare with another graph	correct values read from the graph
A6	**Work with tables**	calculate arithmetic means	appropriate significant figures	
A7	**Work with formulae**	manipulate equations, substitute values	solve equations calculate results	relationship stated or implied

Table 6-9 The analysis section of the audit tool.

Each activity that students had to carry out was given an identifying code based on assessment audit tool (Table 6−10).

Activity in the task	**Code**	**Behaviour**
Identify the independent variables and identify for each four factors which were held constant	C.6	identify dependent and independent variable

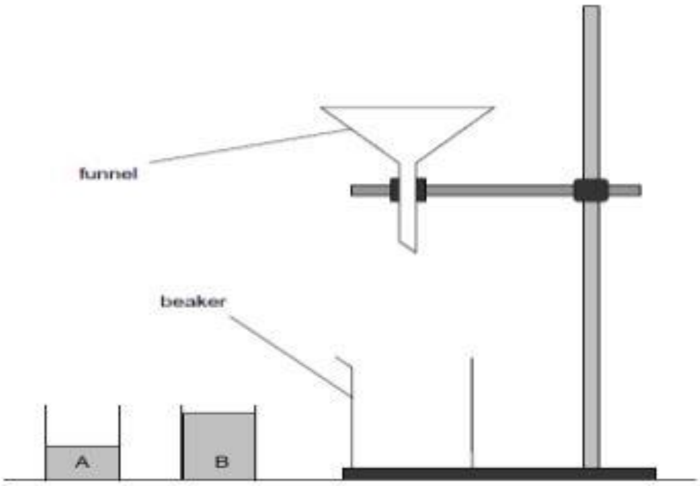
Table 6-10 Coding of the tasks.

Each one of the tasks was coded using the audit tool. The audit tool had four sections, analysis; planning; implementation; and evaluation. An example of a physics task coded using the audit tool (Figure 6−22).

Based on the audit, the tasks were charted to illustrate the distribution of the scientific practices covered (Figure 6−23). These data are from all of the combined tasks in each subject. The individual tasks were also presented in this format. There were 23 assessments in total, distributed between physics, chemistry and biology. They were collectively analysed, and all had a similar distribution of skills. Each task aligned with the learning outcomes.

FLOW RATE TASK I

In this question you will investigate how the mass flow rate of salt passing through the hole in a funnel depends on the mass of salt in the funnel. You may assume that the flow rate is directly proportional to the time taken for unit mass to flow through the aperture.



- Two small beakers containing salt samples
- An empty beaker.
- A top pan balance
- A stopwatch
- A funnel
- A stand and clamp

I1, I3,

P1, I4

1. Measure the mass of salt in each beaker

2. Describe how you might place the salt from the first beaker, A, into the funnel without releasing any salt — P1,

3. Describe how you might measure accurately the time taken for all of the salt to flow from the funnel into the empty beaker — I7

4. Repeat the procedure for the salt in container B — I6

5. Record your data in a suitable form

Figure 6-22 A physics task coded using the audit tool.

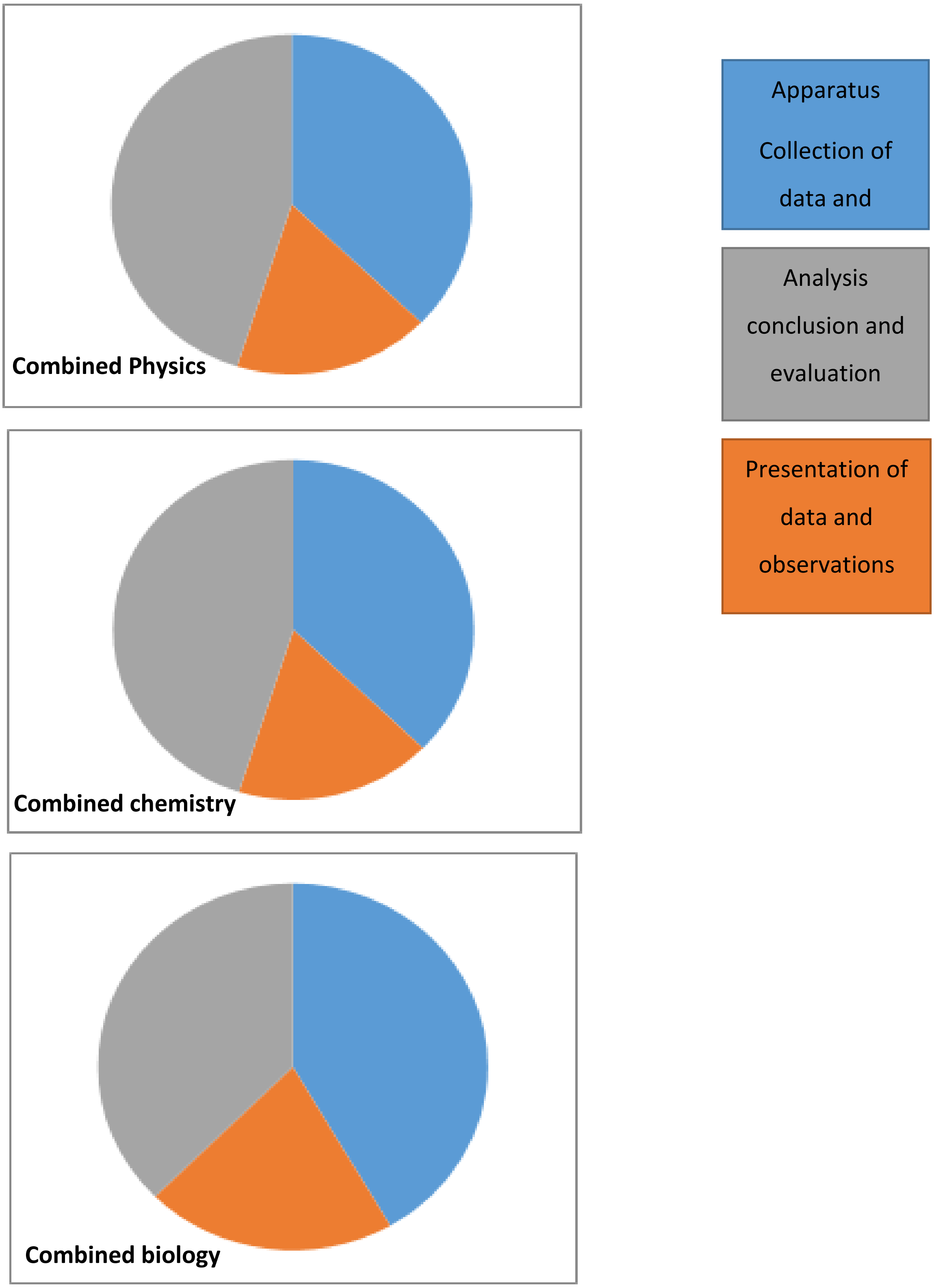


Figure 6-23 Distribution of skills:physics chemistry and biology

6.3.8 Implementation and evaluation

A number of assessment tasks were carried out in the schools and feedback was determined from teachers and students.

During the latter stages of the project, all of the material was made available to the teachers and to the curriculum developers on an editable website. The website was developed with the Joomla content management system. Joomla was chosen as it was possible to allow the teachers and the members of the curriculum development group to add comments to the live site as they wished. The website contained all of the tasks. Each is described in terms of the format, whether the students are assessed in groups or individually and the time period that the assessment is completed over. There is also a description of what is entailed in the task or tasks, along with detail of exactly what equipment and resources are needed by each student. There was a section which contained all of the video material. The videos were of students carrying out the assessments, and of students' and teachers' reflections.

There was a section where each of the examples are matched with a list of outcomes associated with practical science. The outcomes are categorised under three broad headings: data collection and processing, conclusions and evaluations, and use of equipment/safety. There were general comments about how the example ran with the students, including what worked well and what didn't work well, along with any other information necessary to help explain the example or how it was developed.

The students and the teachers were asked what they thought about practical assessment. A video showing students carrying out the practical assessments, with a voice-over of students and teachers talking about the tasks is shown in the e-copy.

Although the teachers and students involved in the network schools only represent a small sample of the school population, their comments provide interesting insights. Both teachers and students generally welcomed the inclusion of a second, practically based, component of assessment. The teachers perceived it as a way of promoting the status of practical work and rewarding students for practical work done throughout the two years. They commented that broadening the range and type of assessment gave a fairer indication of a student's true ability. On the other hand, students saw practical assessment more as a chance to do an examination not reliant on memory or extensive writing. They felt that including practical skills in the assessment would make the examination less daunting. Some mentioned how in other subjects where there was a second component assessment they liked having a proportion of their marks prior to the written paper. Students generally liked the tasks and although many of them were very nervous starting out, they genuinely enjoyed doing them.

The clarity of instruction was critical to performance standards, and many students commented on how they were able to work through the tasks because the instructions were *so clear*. They also liked the fact that although they found some of the tasks challenging, they approved of them for the following reasons: they were able to complete them, and they could see results as they carried out the tasks, which gave them a degree of confidence that they were on track. One group of students talked about the value of doing practical work throughout the period of their course of study. They enjoyed practical science but were conscious of the fact that it was possible to complete Leaving Certificate science without ever doing a practical class and yet not be disadvantaged in the examination. They perceived that this gave *grind school* candidates an advantage as they didn't waste time doing the mandatory experiments; they simply learned them from the text book.

The project was evaluated using the evaluation matchboard methods (Table 6−11).

Quality aspects	
Relevance	There was a need to provide real life examples of the various methods of practical assessment for a variety of reasons. Video material of students carrying out the tasks in school laboratories provided a realistic starting point for the deliberations that was grounded in the reality of Irish classrooms.
Consistency	The project was logically designed. The groups all worked to a common template for the tasks, a common set of criterial were used, and all task were measured against the effectiveness scale.
Expected Practicality	The project was expected to be able to be used in classroom settings
Expected Effectiveness	The project was expected to produce and produce intended outputs- i.e. video material and teacher and student reflections.
Actual Practicality	The product worked well in the classroom settings. The situations were authentic and provided the right setting for the collection of outputs.
Actual effectiveness	Video material and student and teacher reflections for each of the activities was collected.
Evaluation methods	
Screening	An initial screening of the proposed project was carried out with the help of science education experts from the University of Durham.
Focus group (expert appraisal)	The curriculum development group, appraised the project and made suggestions. Three members of the curriculum development group (one each in biology, chemistry, and physics) participated in the research.
Walkthrough	Each of the tasks was carried out by subject matter experts. The tasks were times and tested for feasibility. Adjustments were made prior to use by students.
Try out	The sample practical assessment was carried out in 12 schools. Students were videoed, and teachers and students' reflections were recorded.

Table 6-11 Evaluation matchboard for the assessment project

6.3.9 Key concerns

Equipment

One of the main barriers highlighted by teachers on the project re practical assessment is the difficulties associated with equipment and materials. As the assessment is completely externally assessed, it is not feasible to ask the teacher to set up the equipment, as this would mean that the teachers would have prior notice of the assessment tasks. The teachers involved also voiced concern about the difficulty in ensuring that every student had access to the same level of resources and the extra workload that preparing for Leaving Certificate practical assessment would entail. What equipment will be used? Who will prepare the laboratories and equipment? What will the role of the teacher be? How will it be possible to ensure that students are not disadvantaged because of inadequate equipment or poorly made up solutions or equipment?

The issue of equipment was of particular concern. As a way of overcoming the possible difficulties kits were designed for some of the tasks (Figure 6−24). These kits were completely self-contained, with everything that a student would require to complete the assessment. A laboratory supply company was asked to develop the kits. The advantages of these kits were seen when teachers did not have to be involved in preparing solutions and equipment or in getting the laboratory ready. The kits ensured that each student had access to exactly the same resources.

A biology kit **A chemistry kit** **A sealed kit**

Figure 6-24 Kits provided to students

As part of the design research, each of the tasks was tried out using the kits. This *try out* allowed for some refinements to be made to the teacher designed tasks to ensure the best possible outcome for the students. The result of this level of preparation was that on the day of assessment, everything worked as it was supposed to. Each kit contained everything needed for one student. All that was required of the school was to supply large items of standard equipment, such as retort stands and standard glass beakers.

Process or product?

As discussed in Section 5.3, there are two main forms of practical assessment, direct assessment of practical skills (DAPS) where marks are awarded based on direct observation of a student carrying out a practical activity, and indirect assessment of practical skills (IAPS) where marks are awarded based on a product of the process of practical science.

Both forms of assessment have their relative merits. While DAPS has a high level of validity, it is very costly and time intensive. IAPS on the other hand is more straightforward and less costly, but used on its own is less likely to promote the level and kind of practical work that is desirable. The combination of an element of DAPS with IAPS combines *hands on* with *minds on*.

This raises questions about whether students should be examined individually, DAPS, or in groups by IAPS where a product of the process (a task sheet) is marked. One of the examples used in the project combined both approaches. A group of students carried out a set of practical tasks and completed a task sheet based on their data and observations. Whilst they were completing the tasks, the students were observed by an examiner and awarded marks based on their ability to use the equipment competently and safely. Although the teacher mentions the difficulties in awarding marks based on a judgment of how well a student uses a piece of equipment or makes an observation, it would be possible, given the right set of criteria, for the invigilator, to take on the role of examiner and award some marks based on direct observation of students. Awarding a portion of the mark based on direct observation of students would add to the validity of the examination.

Working in groups

Teachers raised concerns that if students were assessed in groups that they might be tempted to copy one another. In this study, the students just got on with following the instructions and completing the tasks. The tasks in the practical assessments do not rely on recall, all of the information needed to complete the task is given; how well they carry out the instructions and complete the tasks depends on their skills. It is clear in the videos that students were occupied, were absorbed by the tasks. One student comments:

> *The investigations were interesting, there was a good variety, and you didn't get bored. (Student)*

Providing variety to avoid repetition of tasks year on year?

A question emerged concerning task repetition. Teachers wondered if a set of tasks would emerge that were repeated, with slight variations, from year to year and which would then end up being practiced by students. The examples illustrate ways in which a generic set of skills can be assessed, using many different contexts. As long as the set of skills that students are to be assessed on are clearly defined, there are any number of tasks that can be designed to test them. Students will be practicing these generic skills in all of the practical activities that they carry out over the course of their study. Most students liked the fact that the tasks were unrehearsed; only one student said that she would rather be assessed on mandatory experiments that could be practiced for the examination. One student comments:

> *Because you didn't know what you were going to get you didn't have to learn it off so you didn't have to stress about it. (Student)*

Logistics

One of the major barriers to running practical assessment is the logistical difficulty of externally examining groups of small numbers of students during term time. As part of the project, it was possible to gather information on all of the logistical difficulties: the optimum number of students per laboratory; what would be required of the teacher, the management, other teachers; and the effect on the rest of the school during examination time. Data was collected about the numbers of laboratories in each second level school, and the numbers of students studying each of the science subjects. This made it possible to provide an accurate picture of what kind of logistical difficulties the practical assessment would pose, and give a base-line on which to estimate some projected costs. This information was particularly useful in terms of estimating the cost of, including direct assessment versus only indirect assessment.

Assuming:

- 691 schools involved in at least one of the Leaving Certificate science practical examinations.
- **Event:** one 90-minute practical examination in one laboratory
- **Session:** multiple events held at the same time in the same school. 12 students per session
- **Day:** three sessions per lab per day
- All laboratories in a school can be used for each subject.

A projection of the numbers of repeat sessions that would be required in each school for for each subject was made.. For example, in a school that has three laboratories and 120 students doing biology, only 36 (12 per laboratory) could take the examination at one time. i.e. that schol would require 4 separate sessions to accommodate all biology students. These examinations would have to happen at a different time to the chemistry examinations and yje physics examinations.

Figure 6−25 shows the frequency of events for each subject. For example, 47 schools will have to host 10 events in biology.

Further analysis shows that:

For biology 28 schools would complete the exam in 1 day (or less), 111 in 2 days, and 187 in 4 days and so on. Table 6−12 shows the numbers of full days that laboratories would be required: (anomalies are due to rounding up)

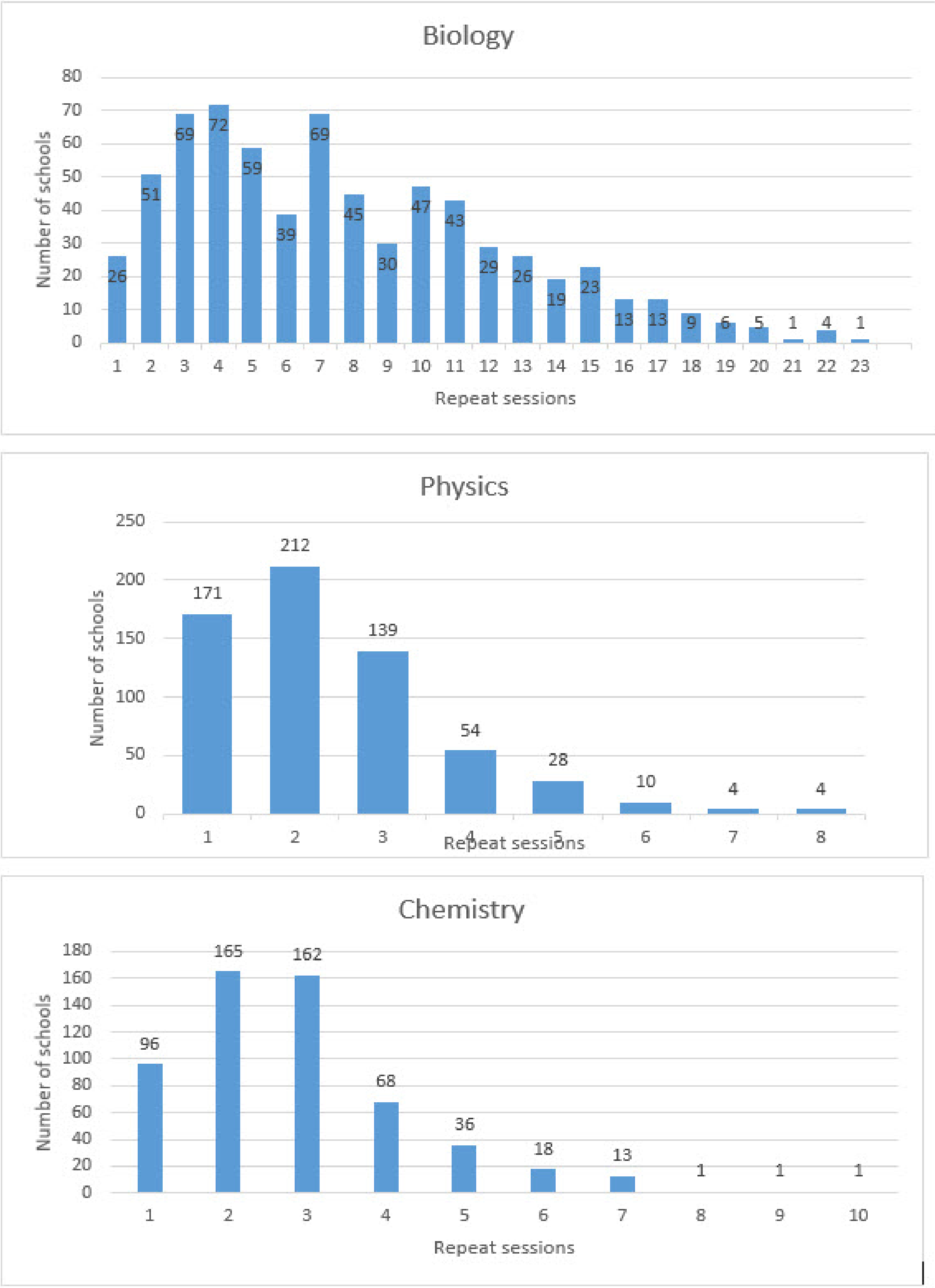


Figure 6-25The number of repeat sessions per school

Numbers of days that laboratories would be required Full days in a school

Full days in school	1	2	3	4	5	6	7	9	10
Biology	28	111	200	187	97	40	14	14	
Physics	532	138	14	7					
Chemistry	476	193	21	7					

Table 6-12 Distribution of numbers of days for schools

This analysis shows the time and lab time that would need to be allocated to this type of assessment.

6.3.10 Conclusions

This project provided valuable information on the applicability of practical assessments in Irish schools for Leaving Certificate. It provided important insights for curriculum developers into what students can demonstrate in a practical examination beyond that contained in a written examination. The teachers and students involved in the project were very positive about the how a second component assessment in science would add to the existing assessment arrangements. Both commented on the benefits of rewarding the practical work done throughout the two years. The examples show that students can demonstrate a comprehensive range of science practical skills appropriate to Leaving Certificate using basic laboratory equipment. The examples worked because they were uncomplicated. As one teacher noted:

> *The key to them working well is that they have to be simple…there's no need for complicated tasks to be able to test a set of skills. (Teacher, assessment project)*

The project did not set out to explore issues such as the levels of scientific complexity of concepts and contexts of practical assessment, or differentiation between Ordinary level and Higher level, rather it set out to provide real examples of what practical science assessment in the senior cycle actually looks like and feels like for teachers and students.

The examples served as tangible representations of practical assessment that enabled the discussion to reference specific examples of what works well and what does not. Three of the teachers involved in the project were members of the curriculum development group, and were able to relay their own experiences directly into the discussion on practical assessment in the revised specifications.

Following extended discussions, the curriculum development group proposed that:

- Assessment would not include an interview of the student. As individual examination would not be feasible from a logistics point of view.
- Assessment would be a combination of direct and indirect assessment
- The indirect assessment did not provide enough evidence of student's practical abilities. Although a certain amount could be inferred from the data that a student collected, the curriculum developers felt very strongly that direct assessment of a group of students was possible and desirable.
- A limited list of standard laboratory equipment would be used for the tasks.
- Students would select the appropriate equipment on the day. It was shown that a lot can be done with a standard set of school laboratory equipment. In some of the tasks in the examples, students were provided with everything they needed, however, the students' ability to choose appropriate apparatus is an important skill.
- Each year, twelve different examination papers would be prepared for each subject to allow for each student in the room to have a different set of tasks.
- This level of variety was considered necessary to ensure that no student had an advantage if they completed the assessment at a later time than their colleagues. Given the number of repeat events
- Direct assessment will be by an external examiner, a local science teacher will be on call for the duration of the examination.

7 Conclusions

This chapter summarises the key findings from the study and addresses the aims of the research. Significant changes in modern society require learners to have a wide, adaptive knowledge base and understanding to enable them to be active participants in the communities in which they live and work. A recent OECD review, citing a number of international sources, suggests that learners need to have opportunities to (i) acquire relevant knowledge, (ii) develop a range of critical skills, including both fundamental access skills such as literacy and numeracy, and higher order skills such as creativity, critical thinking, problem solving, communication and collaboration; (iii) develop behaviours, attitudes and values, including abilities that enable the learner to care for him/herself, to act as a responsible citizen, and to be adaptable and resilient; and (iv) learn how to learn: to become aware of one's own learning styles and to acquire the ability to develop and enhance one's own learning approaches.

Many countries, including Ireland, see forward thinking curricula as a lever for greater equity in educational outcomes for all learners. Increasingly, reviews of educational systems focus not only on overall educational performance, but also on the extent to which school systems are serving the needs of diverse learners, and equity in the achievement of particular groups. In Ireland, more than 90% of students remain in school to complete upper second level education; greater numbers of students with diverse learning needs are staying in education for longer. In a time of significant social, economic and cultural changes, it is increasingly important that learners take responsibility for their own learning, and develop key competences that enable them to navigate an uncertain world.

Over the last two decades, there has been discussion and review of the Leaving Certificate programme in Ireland, leading ultimately to the revised Leaving Certificate programme and new specifications for science subjects, Physics, Chemistry and Biology. The rationale for change in senior cycle has been reviewed in this thesis (Chapter 2). Also, the thesis includes a description of the process of curriculum development in Ireland, in particular in the Leaving Certificate sciences.

Review and analysis of selected international second-level curricula (Chapter 3) have shown a move away from the specification of large amounts of content towards curricula that are written as learning outcomes, into which development of identified 21st century skills are embedded. Ireland has followed these international trends, and the revised specifications for Leaving Certificate biology, chemistry and physics share these commonalities. Rich, open learning outcomes allow for flexibility and for teachers to use their expertise and professional judgement in planning for teaching, learning, and assessment. Specifications that describe a process rather than a product of learning are new to teachers in Ireland, and careful consideration must be given of the best way to provide guidance so that learning outcomes are interpreted in the way that the developers intended. The nature of the support material provided with the subject specifications is critical to the professional development of teachers and to the success of revised curricula.

Curriculum coherence is regarded as a critical factor in ensuring the alignment of the developed, the implemented, and the enacted curriculum. Reducing the amount of atomisation and specificity of a curriculum is considered necessary to provide teachers with flexibility and space to use their professional judgement in teaching, learning and assessment, and to promote deeper engagement by learners as they rely less on formulaic approaches to knowledge and understanding, and more on metacognition and innovative learning approaches. However, reduced specification of content and teaching and learning approaches means increased responsibility for teachers in selecting what is taught. This added responsibility charges them with the task of providing learning experiences that develop key skills in learners as well as developing discipline knowledge. When flexibility of teaching and learning is built into an outcomes based curriculum, there is potential for misinterpretation of the learning intentions which has implications for curriculum coherence.

The aim of the research presented in this thesis was to work with teachers and schools to identify the strategies and describe the kind of support that will enable teachers to translate and communicate learning outcomes of revised curricula in upper second level biology, chemistry and physics in the way that curriculum developers intended, and in doing so, achieve curricular coherence across schools.

7.1 Key findings

There have been extensive reviews in the past of the Leaving Certificate (established) program. The reviews arose out of concerns that the Leaving Certificate (established) is dominated by the Leaving Certificate examination, which adversely affects the experience of learners at this stage of their education. The reports and the consultations that were part of the review often cited the assessment as being to blame for narrowing the curriculum; however, this researcher argues that it is the curriculum that narrows the range and type of assessment.

The development of the new specifications for Leaving Certificate Science subjects – Physics, Chemistry and Biology – has seen the statement of the learning as Learning Outcomes. Learning outcomes are multi-layered descriptions of the learning process as well as the learning content. Their interpretation requires an understanding of the complex process that is used to construct them.

An organising framework was developed for the learning outcomes as a development tool in discussion of the curricula. Anderson and Krathwohl's 2-dimensional framework was further expanded to give a 3-dimensional framework of the knowledge dimension, the cognitive dimension and the embedded key skill. Based on the structure of each learning outcome, it can be categorised on each of the three dimensions. The knowledge dimension is divided into factual, conceptual, procedural and metacognitive knowledge while the cognitive dimension is characterised into 6 sub headings – remember, understand, apply, analyse, evaluate and create. The embedded key skills were under the headings of being personally effective, communicating, critical and creative thinking, information processing and working with others.

The organising framework was effective in providing an overview of the range and depth of knowledge and skills during the process of curriculum development. It was also used with a small group of teachers in relation to interpretation of learning outcomes. The level of agreement on the categorisation of the learning outcomes between the teacher and the researcher was considerable. However, where the learning outcome closely resembled something that students currently do, there was a tendency for teachers to categorise the outcome as it is currently taught, rather than according to the taxonomy of the revised specification. As the order of the outcomes became higher, for example debate an issue, the greater the level of discrepancy. That is to be expected, and does not necessarily mean that the teachers have misinterpreted the outcomes; what it highlights is that the *learning intention* (as opposed to how to teach it) must be made very clear where there is an outcome that can be interpreted in multiple ways.

Further development of the organising framework gave rise to the 3-axis scale of assessment item demand. Applying a similar taxonomy to assessment provides a visible connection between curriculum, pedagogy and assessment. The combination of the knowledge dimension with the cognitive process dimension allows measurement of outcomes that are more complex than simply pieces of discrete content. Following extensive review of literature on assessment, the 3-axis scale of assessment item demand was developed which had the knowledge dimension, the cognitive process dimension and an assessment dimension, with 4 sub-headings of (i) knowledge and understanding of facts, principles, concepts, and methods; (ii) application of knowledge to familiar and unseen contexts; (iii) manipulation, analysis and evaluation of data and (iv) use of arguments based on evidence. The 3-axis scale of assessment item demand is simplistic in its design, but it facilitated the mapping of assessment items. Using this tool over a range of items, a teacher can be confident that they have assessed an appropriate range of knowledge and skills, and that all of the assessment criteria are being met.

To demonstrate how learning outcomes can translate into classroom practice, a research design project was undertaken with schools – called *Asteroids, Impacts and Craters* - in which learners developed key skills as they encountered physics concepts in an authentic context. This project demonstrated how learning outcomes could be translated into classroom practice; it gave real examples illustrating how key skills, and higher order thinking skills were embedded in learning outcomes; it also showed the type of evidence that would demonstrate the achievement of learning outcomes and reaching personal targets. Change is usually associated in teachers' minds with extra work and stress, however the teachers involved in the *Asteroids and Impacts* project enjoyed the experience. The innovative teaching methods resulted in students being more engaged as they found the context interesting, and the learning relevant to life outside school. Whilst acknowledging that change is stressful, the significant positive consequences of the new specifications should be highlighted and communicated to teachers, learners and parents.

The second design based research project, entitled *Assessment of practical science* provided examples of different ways of assessing practical science to support the discussions and deliberations of the curriculum developers on how practical assessment could work. It generated examples of different kinds/elements of practical science assessment, and the content and items (tasks/questions etc.) that the different assessments gave rise to. Working with schools provided a view of what the different kinds/elements of practical science assessment looked like in practice and as a result of this, the cost, both financial and logistical, of running large scale practical assessment, could be determined.

7.2 Implications and recommendations

Curriculum development

Consideration of the nature of the learning outcomes should go far beyond the content. A focus on discipline knowledge content at the expense of skills and process will be a barrier to effective curriculum implementation unless a considered effort is made to support teachers' interpretation and communication of learning outcomes.

When developing a specification, it is important to examine the complete specification. The use of frameworks, such as the organising framework and the three scale assessment framework developed in this study, can provide an ongoing picture of the totality of the curriculum, and the relationship between the learning outcomes, the learning intentions and the assessment.

There are some caveats about the organising framework. It assumes that the curriculum is a rational linear planning process, which of course it is not. Critics will argue that assigning numbers to learning outcomes is a paper exercise that relays little information, as the context in which the outcomes are achieved is the key determinant on the skills and knowledge that are developed by the learner.

The framework is based on the assumption that all learning outcomes are capable of being specified in advance, and that success depends on a set of predictable outcomes that are the same for all learners being achieved. The framework would be counterproductive if using it restricted spontaneity and flexibility. It is the role of the teacher to achieve a balance between over-planning and lack of organisation. The framework may be useful as a retrospective tool to critically examine a lesson, a task or a unit of instruction. It is also important to note that planning can provide direction without overbearing control. Planning may bring coherence to teaching and learning, but should not control it.

Interpretation and implementation

Curriculum development should be an ongoing process informed continually by outputs from research and classroom trialling. School-based evaluation of different aspects of curricula will inform the ongoing process, and provide important information for review and refinement.

Curriculum materials intended to promote teacher learning, in addition to student learning, should be developed. These curriculum materials should emerge from research and practice and be directed towards developing teachers' pedagogical content knowledge. The material should be presented with the specification that its purpose is to help to help interpret learning outcomes and design innovative teaching, learning and assessment. A variety of sample assessment material should communicate the learning intentions, and illustrate the evidence that will demonstrate the extent to which learning outcomes have been achieved.

There is evidence that one of the main barriers to successful implementation of change is lack of understanding of the rationale for change, and a lack of belief about the benefit of change. CPD that educates teachers about research evidence in curriculum and assessment development will help to build teachers beliefs in new curricula. New developments should be placed in the context of background research and global change. Just as teachers will be expected to adapt their teaching away from transmission towards transaction, so the model of CPD should also change. Teachers should be encouraged to engage in discussion about learning outcomes and their assessment; trial ideas in their classroom and report back on their experiences. This level of activity and engagement will require time (as there is no quick fix for the extent of the changes that are on the horizon) however, time invested in this kind of CPD will pay dividends in the long term, as teachers' action research and reflection will feedback into the ongoing process of curriculum and assessment development.

Assessment

Assessment plays a major part in the planning for teaching and learning. Assessment that aligns closely with the learning outcomes and which provides a clear indication of what students should know and be able to do at each stage of their progression through a course will be critical in ensuring curriculum coherence. It is crucial that CPD provides extensive training on assessment, and the role of assessment in learning. When learning outcomes are open and non-prescriptive, an organising framework for assessment such as the one described in this thesis can provide a checking tool to ensure that assessment validly measures the intended learning. To ensure alignment of assessment with the learning outcomes and the aim of the specifications, assessment should be designed to measure the extent to which individual learners have achieved learning outcomes, not just how much they know. Extensive summative and formative assessment material should be presented with each specification so that teachers, learners and parents fully understand the role of assessment in learning as well as the kind of evidence required to show that a learning outcome has been achieved.

Practical assessment will add significantly to the written assessment if the science process assessed in each mode is clearly defined. The written examination will assess the higher order skills of investigation and inquiry such as creating and evaluating; the practical examination will assess manipulative skills and conceptual and procedural understanding by assessing performance of, rather than knowledge about, experimental science. Although direct assessment of practical skills is expensive it is essential to ensure alignment of teaching and learning with the aim and objectives of the specification.

7.3 Concluding remarks

Ireland is at a critical stage in science education reform. A revised specification for junior cycle science is due for implementation in September 2016, and new specifications for Leaving Certificate chemistry, biology and physics are scheduled for implementation in September 2018. The reforms at both senior cycle and junior cycle emphasise the development of key skills, and deeper engagement with both the process of science and the theoretical concepts that underpin science knowledge. More responsibility for learning and skills development is devolved to learners, with teachers acting as facilitators of learning. This presents a considerable challenge for everyone involved in the education the system, however the reforms also offer a unique opportunity to reposition science education as a lever for improvement and inclusion. There is potential to harness the expertise and experience of teachers to inform and enhance science education policy, practice and research, and place Ireland at the forefront of STEM education worldwide.

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Appendices

1 Key Skills Framework

Key Skill	Elements
Information processing	• Accessing information from a range of sources • Selecting and discriminating between sources based on their reliability and suitability for purpose • Recording, organising, summarising and integrating information • Presenting information using a range of information and communication technologies
Critical and creative thinking	• Examining patterns and relationships, classifying and ordering information • Analysing and making good arguments, challenging assumptions • Hypothesising and making predictions, examining evidence and reaching conclusions • Identifying and analysing problems and decisions, exploring options and alternatives, solving problems and evaluating outcomes • Thinking imaginatively, actively seeking out new points of view, problems and/or solutions, being innovative and taking risks
Communicating	• Analysing and interpreting texts and other forms of communication • Expressing opinions, speculating, discussing, reasoning and engaging in debate and argument • Engaging in dialogue, listening attentively and eliciting opinions, views and emotions • Composing and performing in a variety of ways • Presenting using a variety of media

Working with others	• Working with others in a variety of contexts with different goals and purposes • Identifying, evaluating and achieving collective goals • Identifying responsibilities in a group and establishing practices associated with different roles in a group (e.g., leader, team member) • Developing good relationships with others and a sense of well-being in a group • Acknowledging individual differences, negotiating and resolving conflicts • Checking progress, reviewing the work of the group and personally reflecting on one's own contribution
Being personally effective	• Being able to appraise oneself, evaluate one's own performance, receive and respond to feedback • Identifying, evaluating and achieving personal goals, including developing and evaluating actions plans • Developing personal qualities that help in new and difficult situations, such as taking initiatives, being flexible and being able to persevere when difficulties arise • Becoming confident and being able to assert oneself as a person

Key Skill	Elements	Learning outcomes students should be able to:
Information processing	Accessing information from a range of sources	• recognise the wide range of information sources that is available both within their schools, at home and beyond • access information quickly in written materials by strategies such as using table of contents, glossaries, summaries at the end of chapters and so on • use library catalogues and referencing systems to find books and other materials • access new information quickly through using dictionaries, reference materials and the internet • navigate the internet to find specialist sites related to a topic they are studying • use people as well as hardcopy/electronic sources as sources of information
	Selecting and discriminating between sources based on their reliability and	• develop well-focused questions to guide their selection of sources • evaluate the reliability and credibility of sources using criteria such as the authorship, affiliation, currency, bias, expertise of the author • explain and justify the basis for their selection
	Recording, organising, summarising and integrating information communication	• use systematic observational and note-taking techniques • keep well-ordered notes so that they are readily accessible for future use • identify main ideas in a text using both prior knowledge and clues within the text (e.g., headings and sub-headings, paragraphing, conclusions) • use a range of methods for organising information, e.g. lists, concept-maps, flow diagrams • create summaries of information in their own words • integrate information from different sources by systematically examining similarities and differences between them and looking for alternative perspectives
	Presenting information using a range of information and communication technologies	• make choices about what medium to use when presenting information, taking account of audience, purpose and available facilities • explain and justify their choices • use a range of ICT tools effectively (e.g., PowerPoint, video clips, digital camera)

<table>
<tr><th>Key Skill</th><th>Elements</th><th>Learning outcomes
Students should be able to:</th></tr>
<tr><td rowspan="5">Critical and creative thinking</td><td>Examining patterns and relationships and classifying and ordering information</td><td>• use a range of methods for identifying patterns in information and ideas, e.g., lists, networks, hierarchies, matrices, flow diagrams, graphs, maps, etc.
• explain the relationships between wholes and parts
• systematically examine similarities and differences as the basis for comparing and contrasting
• be able to group objects, events or ideas according to attributes and explain the basis for their classification
• be able to re-classify by changing the basis for their classification</td></tr>
<tr><td>Analysing and making good arguments, challenging assumptions</td><td>• understand the difference between opinion, reasoned judgment and fact
• judge the credibility of an information source using criteria such as authorship, currency, potential bias
• recognise components of an argument such as assumptions, reasons, counterarguments and conclusions
• use these components when making their own arguments
• recognise the effects of using emotive words in arguments</td></tr>
<tr><td>Hypothesising and making predictions, examining evidence and reaching conclusions</td><td>• develop a line of reasoning from prediction/evidence/conclusion
• understand the need to isolate and control variables in order to make strong causal claims
• describe the relationship between variables
• point out the limits of correlational reasoning
• draw generalisations and be aware of their limitations</td></tr>
<tr><td>Identifying and analysing problems and decisions, exploring options and alternatives, solving problems and evaluating outcomes</td><td>• recognise that problem solving and decision making can be approached systematically
• use techniques to help explore alternative solutions and options such as brainstorming, visualisation, listing positive/negative/interesting attributes
• predict the likely consequences of options and alternatives and systematically examine the pros and cons of each
• recognise the impact of real-world constraints
• evaluate outcomes of solutions and decisions both in the short and long term
• appreciate the likely bias in analysing by ‘hindsight’</td></tr>
<tr><td>Thinking imaginatively, actively seeking out new points of view, problems and/or solutions, being innovative and</td><td>• recognise that different mind-sets are associated with different forms of thinking (e.g., letting ideas flow, building up associations, suspending judgment in order to produce ideas, are often associated with creative thinking)
• be motivated to seek out alternative perspectives and viewpoints and to reframe a situation
• be willing to take risks and to learn from mistakes and failures
• be persistent in following through ideas in terms of products and/or actions
• develop a strong internal standard in relation to the merits of their own work</td></tr>
</table>

Key Skill	Elements	Learning outcomes Students should be able to:
Communicating	Analysing and interpreting texts and other forms of communication	• analyse texts from several perspectives (e.g., intended audience, genre, viewpoint of the author, cultural/ historical viewpoint) • use agreed frameworks for analysing texts and other forms of communication (e.g., the composition of film, visual art, computer graphics) • check the reliability and credibility of sources, and critically analyse arguments and claims • identify how language and other forms of communication are used for persuasion and rhetoric (e.g., for political argument, advertising, propaganda) • identify and explain their own personal responses to text and other forms of communication
	Expressing opinions, speculating, discussing, reasoning and engaging in debate	• recognise the importance of speculation and argument as forms of dialogue for learning and for leisure • be sufficiently open-minded and curious to engage in speculation and argument • marshal and defend an argument while listening to opposing points of view • recognise the possible emotional impact of a robust argument on others
	Engaging in dialogue, listening attentively and eliciting opinions, views and emotions	• listen attentively to what others have to say • elicit opinions, views and emotions from others through the appropriate use of questioning and responding strategies • develop empathy by imagining the situation from other peoples' point of view • respond perceptively to contributions made by others
	Composing and performing in a variety of different ways	• identify a range of genres, their purposes and styles • compose in a variety of genres, showing the capacity to plan, draft and revise • express meaning and emotions through a range of performances (e.g., visual art, drama, music, design and graphics)
	Presenting using a variety of media	• identify the main purpose of a communication and relate its form and nature to the purpose • make choices about what medium to use, taking account of audience and purpose • make appropriate adjustments depending on whether they are making an oral or a written presentation • use of range of general ICT tools effectively (e.g., PowerPoint, video clips, and more specialized ICT if appropriate) • make appropriate use of dramatic modes of presentation (e.g., role-play, storytelling) • explain and justify choices

Key Skill	Elements	Learning outcomes Students should be able to:
Working with others	Working with others in a variety of contexts with different goals and purposes	• recognise that working with others is an intrinsic part of home, school, work and leisure • explore the contexts in which they work in groups (e.g., learning groups, sports groups, family groups) and examine the differences between them • recognise the need to respond flexibly in different contexts
	Identifying, evaluating and achieving collective goals	• work in pairs and larger groups to plan the work of the group • co-operate with other members of the group to identify collective goals • co-operate with group members to identify how different roles can contribute to the overall goals • communicate ideas and needs within the group • agree action plans for achieving the goals • agree methods for keep each other informed of progress
	Identifying responsibilities in a group and establishing practices associated with	• help to break tasks down into parts as a way of sharing the work of the group • take on the responsibilities of the role whether as a team member or a team leader • recognise how his/her role blends with the responsibilities of others in the group • express views about how the work of the group is progressing
	Developing good relationships with others and a sense of well-being in the group	• listen carefully to other points of view • develop empathy and see alternative perspectives • express emotion in appropriate ways • help others to feel included in the group • help motivate the group to persist in the face of difficulties • celebrate the achievements of the group
	Acknowledging individual differences, negotiating and resolving conflicts	• respect the rights and views of others in the group • recognise that different positions and viewpoints are likely to be adopted and expressed • identify areas of agreement and disagreements among the different positions • make suggestions about possible compromises and alternative ways forward • agree ways to resolve conflict
	Checking progress, reviewing the work of the group, and personally reflecting on one's own contribution	• keep to deadlines and agreed plans • monitor progress in the group against agreed plans • negotiate individual responsibilities • critically evaluate and change the approach of the group if necessary • participate in evaluating the outcomes against the collective goals • reflect on their own contribution to the group and identify strengths and weaknesses • identify ways of further improving their skills in working with others

Key Skill	Elements	Learning outcomes Students should be able to:
Being personally effective	Being able to appraise oneself, evaluate one's own performance, receive and respond to feedback	• identify their own aspirations and what they would like to achieve • set time aside to take stock of current achievements and, with the help of others, to engage in an honest appraisal of their strengths and weaknesses • show the resilience to receive and make sense of feedback • identify areas for action and move on
	Identifying, evaluating and achieving personal goals, including developing and evaluating action plans	• set realistic personal goals and targets to be achieved within a time frame • construct action plans to help reach the targets and identify methods for monitoring how well the plans are working (e.g., deadlines, feedback from others) • identify any help and resources that will be needed to implement the plans and reach the targets • within a specific time frame, evaluate the extent to which the targets have been reached and engage in personal reflection on the process of setting goals and targets • take responsibility for decisions and actions, making informed choices • identify strategies for making informed choices
	Developing personal qualities that help in new and difficult situations, such as taking initiatives, being flexible, being reliable and being able to persevere when difficulties arise	• recognise that new situations are likely to be uncertain and present personal challenges • take the initiative on some occasions and not always leave it to others • be flexible and be prepared to try a different approach • show that they are reliable in following through with tasks and undertakings • show persistence and not give up at the first sign of difficulty
	Confident and able to assert oneself as a person	• recognise the need to make their 'voices' heard in appropriate ways • become more skilful at 'reading' social situations and responding appropriately • celebrate their achievements • develop strategies for maintaining a positive sense of self in the face of disappointment and frustration

2 The Irish Education System

First Level

The Irish education system starts at birth with non-compulsory period of pre-school education. *Aistear*, the early childhood framework, uses four interconnected themes to describe the content of children's learning and development: Well-being; Identity and Belonging; Communicating; and Exploring and Thinking.

Although compulsory education does not start until age 6, most children in Ireland start formal school in the September following their fourth birthday. The primary curriculum is divided into the following areas:

- Language
- Mathematics
- Social, Environment and Scientific Education
- Arts Education, including Visual Arts, Music and Drama
- Physical Education
- Social, Personal and Health Education

Second Level

Second level education consists of a three year Junior Cycle (lower secondary) followed by a two or three year Senior Cycle (upper secondary), depending on whether the optional Transition Year is taken. A state examination is taken at the end of Junior Cycle.

Transition Year, a major innovation in Irish education, is an optional year that immediately follows on from junior cycle. It provides an opportunity for students to experience a wide range of educational experiences, including work experience. There is an emphasis on personal development, social awareness and skills for life. There is no formal summative examination.

During the final two years of senior cycle, students take one of three programmes each leading to a state examination – the Leaving Certificate established, the Leaving Certificate Vocational Programme or the Leaving Certificate Applied. The Leaving certificate (established) examination is the gateway for Irish students to third level education and work. It is typically taken when students are 17-19 years of age. Syllabi are available in 34 subjects, offered at two levels, Ordinary level and Higher level. Irish language and mathematics are also offered at foundation level. Students who follow the established Leaving Certificate are required to take at least five subjects, one of which must be Irish language.

3 Learning outcomes glossary

Verb	**Description**
Analyse	study or examine something in detail, break down in order to bring out the essential elements or structure; identify parts and relationships, and to interpret information to reach conclusions
Annotate	add brief notes of explanation to a diagram or graph
Apply	select and use information and/or knowledge and understanding to explain a given situation or real circumstances
Appraise	evaluate, judge or consider text or a piece of work
Appreciate	recognise the meaning of, have a practical understanding of
Brief description/ explanation	a short statement of only the main points
Argue	challenge or debate an issue or idea with the purpose of persuading or committing someone else to a particular stance or action
Calculate	obtain a numerical answer showing the relevant stages in the working
Classify	group things based on common characteristics
Comment	give an opinion based on a given statement or result of a calculation
Compare	give an account of the similarities between two (or more) items or situations, referring to both (all) of them throughout
Consider	describe patterns in data; use knowledge and understanding to interpret patterns, make predictions and check reliability
Construct	develop information in a diagrammatic or logical form; not by factual recall but by analogy or by using and putting together information
Contrast	Detect correspondences between two ideas
Convert	change to another form

Verb	Description
Criticise	state, giving reasons the faults/shortcomings of, for example, an experiment or a process
Deduce	reach a conclusion from the information given
Define	give the precise meaning of a word, phrase, concept or physical quantity
Demonstrate	prove or make clear by reasoning or evidence, illustrating with examples or practical application
Derive	arrive at a statement or formula through a process of logical deduction; manipulate a mathematical relationship to give a new equation or relationship
Describe	develop a detailed picture or image of, for example a structure or a process, using words or diagrams where appropriate; produce a plan, simulation or model
Determine	obtain the only possible answer by calculation, substituting measured or known values of other quantities into a standard formula
Differentiate	recognize or ascertain what makes something different
Discuss	offer a considered, balanced review that includes a range of arguments, factors or hypotheses; opinions or conclusions should be presented clearly and supported by appropriate evidence
Distinguish	make the differences between two or more concepts or items clear
Estimate	give a reasoned order of magnitude statement or calculation of a quantity
Evaluate (DATA)	collect and examine data to make judgments and appraisals; describe how evidence supports or does not support a conclusion in an inquiry or investigation; identify the limitations of data in conclusions; make judgments about the ideas, solutions or methods

Verb	Description
Evaluate (ethical judgement)	collect and examine evidence to make judgments and appraisals; describe how evidence supports or does not support a judgement; identify the limitations of evidence in conclusions; make judgments about the ideas, solutions or methods
Explain	give a detailed account including reasons or causes
Examine	consider an argument or concept in a way that uncovers the assumptions and interrelationships of the issue
Find	general term that may variously be interpreted as calculate, measure, determine etc.
Formulate	Express the relevant concept(s) or argument(s) precisely and systematically
Group	identify objects according to characteristics
Identify	recognise patterns, facts, or details; provide an answer from a number of possibilities; recognize and state briefly a distinguishing fact or feature
Illustrate	use examples to describe something
Infer	use the results of an investigation based on a premise; read beyond what has been literally expressed
Investigate	observe, study, or make a detailed and systematic examination, in order to establish facts and reach new conclusions
Interpret	use knowledge and understanding to recognize trends and draw conclusions from given information
Justify	give valid reasons or evidence to support an answer or conclusion
List	provide a number of points, with no elaboration
Measure	quantify changes in systems by reading a measuring tool

Verb	Description
Model	generate a mathematical representation (e.g., number, graph, equation, geometric figure) for real world or mathematical objects, properties, actions, or relationships
Order	describe items/ systems based on complexity and/or order
Outline	give the main points; restrict to essentials
Plot	
Predict	give an expected result of an event; explain a new event based on observations or information using logical connections between pieces of information
Prove	use a sequence of logical steps to obtain the required result in a formal way
Provide evidence	provide data and documentation that support inferences or conclusions
Recognise	identify facts, characteristics or concepts that are critical (relevant/appropriate) to the understanding of a situation, event, process or phenomenon
Recall	remember or recognize from prior learning experiences
Relate	associate, giving reasons
Sketch	represent by means of a diagram or graph (labelled as appropriate); the sketch should give a general idea of the required shape or relationship, and should include relevant features
Solve	find an answer through reasoning
State	provide a concise statement with little or no supporting argument
Suggest	propose a solution, hypothesis or other possible answer
Synthesise	combine different ideas in order to create new understanding
Understand	have and apply a well-organized body of knowledge
Use	apply knowledge or rules to put theory into practice