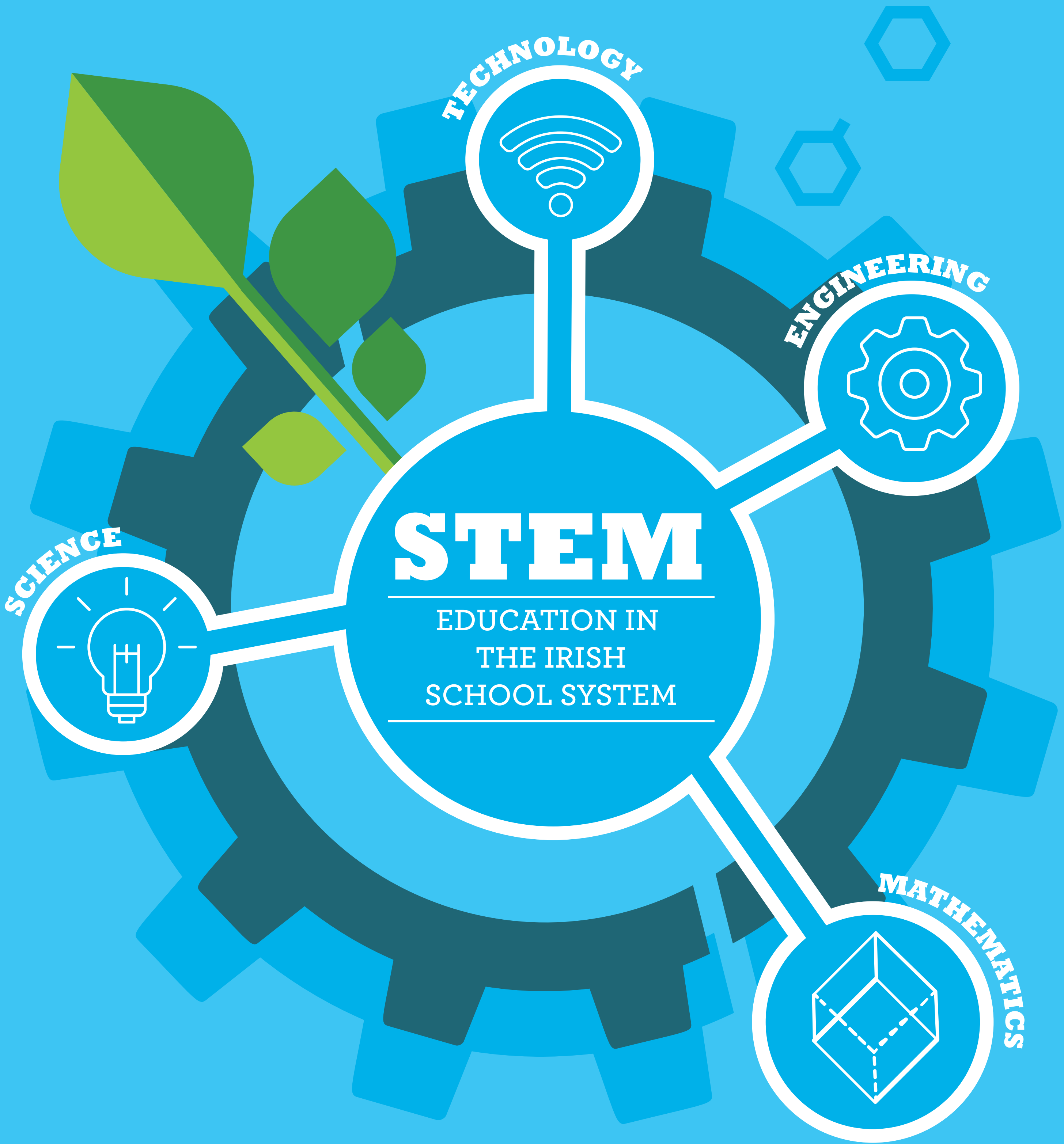

A Report on Science, Technology, Engineering and Mathematics (STEM) Education

Analysis and Recommendations

The STEM Education Review Group

November 2016

FOREWORD

In recent years, Governments of advanced nations across the world have placed a particular emphasis on improving the quality of education in Science, Technology, Engineering and Mathematics (STEM). This reflects the critical importance of STEM disciplines for modern society. They empower our citizens in so many important ways. Science and Mathematics provide answers to the fundamental questions of nature and enable us to understand the world around us. Expertise in STEM disciplines is necessary to drive our economic ambitions, support innovation and provide the foundations for future prosperity. Knowledge-based economies are particularly dependent on the quality and quantity of STEM graduates.

Providing STEM Education of the highest quality is essential if Ireland is to deliver on its ambitions to be a hub of technological creativity and an innovation leader. 'Innovation 2020', Ireland's strategy for Research and Development, Science and Technology, highlights the critical importance of excellence in STEM Education to ensure the continuous development of a pipeline of talent to support both Foreign Direct Investment (FDI) and an active ecosystem for indigenous start-ups.

Driven by these considerations, and conscious of concerns expressed from a range of sources regarding the 'quality and quantity of the STEM pipeline' in Ireland, the then Minister for Research and Innovation, Seán Sherlock TD, established a STEM Education Review Group to carry out a comprehensive review of STEM Education in Irish schools. I had the privilege of chairing the Review Group (full membership given in Appendix I) appointed by the Minister to carry out this work.

The preparation of this Report drew upon the expertise of many individuals and organisations and involved significant consultation with a broad range of stakeholders. In addition to the specialist expertise of all members of the Review Group, contributions were solicited from members of the public, academic and educational institutions, and professionals in the education sector and their representative bodies.

I wish to thank to all the organisations, institutions and individuals who made valuable contributions to this work. In particular, I would like to express my sincere gratitude to the members of the STEM Education Review Group who worked diligently over an extended period to complete this work. I look forward to seeing their efforts translated into significant enhancements of the STEM learning experience for students in Irish Schools.

Prof Brian MacCraith MRIA FInstP

Chair, STEM Education Review Group

CONTENTS

List of figures and tables

Our vision is to provide students in Ireland with a STEM education experience of the highest international quality; this provision should underpin high levels of student engagement, enjoyment, and excellent performance in STEM disciplines.

EXECUTIVE SUMMARY

Science, Technology, Engineering and Mathematics (STEM) are critically important disciplines for modern society. They empower our citizens in so many important ways. Science and Mathematics provide answers to the fundamental questions of nature and enable us to **understand the world** around us. STEM disciplines of knowledge enable us to measure, analyse, design and **advance our physical environment** and enhance our quality of life, especially through developments in healthcare. Expertise in STEM subjects is necessary to **drive our economic ambitions**, support innovation and provide the **foundations for future prosperity**. Knowledge-based economies are particularly dependent on the quality and quantity of STEM graduates. Modern democracies require scientifically-literate citizens in order to **make well-informed decisions** regarding major global issues such as climate change, sustainability, energy, and food security.

Providing STEM Education of the highest quality is essential if Ireland is to deliver on its ambitions to be a hub of technological creativity and an innovation leader. Innovation 2020, Ireland's strategy for Research and Development, Science and Technology, highlights the critical importance of excellence in STEM Education to ensure the continuous development of a pipeline of talent to support both Foreign Direct Investment (FDI) and an active ecosystem for indigenous start-ups.

Driven by these considerations, and conscious of concerns expressed from a range of sources regarding the 'quality and quantity of the STEM pipeline' in Ireland, the then Minister for Research and Innovation, Seán Sherlock TD, established a STEM Education Review Group to carry out a comprehensive review of STEM Education in Ireland.

The STEM Education Review Group adopted the following Terms of Reference upon which it would focus its work, the scope of which was confined to Primary and Post-Primary education:

- The preparation of teachers (at 1st and 2nd Level) for STEM education (so-called Initial Teacher Education)
- The best methods of supporting the current cohort of STEM Teachers already in the system, with a particular focus on Continuing Professional Development
- The introduction of new teaching and learning modalities that would enhance STEM education
- The use of digital technologies to enhance learning
- The promotion of STEM careers and methods to enhance the engagement of students in STEM subjects

These Terms of Reference reflect a clear focus on (i) teacher quality (reflecting the famous quotation from the 2007 McKinsey report on the world's best-performing school systems: "the quality of an education system can never exceed the quality of its teachers"), (ii) implementation of best methods to enhance learning, and (iii) improving awareness of STEM careers.

The preparation of this Report drew upon the expertise of many individuals and organisations and involved significant consultation with a broad range of stakeholders. In addition to availing of the specialist expertise of all members of the Review Group, contributions were solicited from members of the public, academic and educational institutions, and professionals in the education sector and their representative bodies. A public consultation event, which was

EXECUTIVE SUMMARY

held at the Royal Irish Academy (RIA) on April 17th, 2014, was particularly useful in highlighting many of the key issues that need to be addressed in order to significantly improve STEM education in Ireland.

A detailed analysis of the current state of STEM Education in the Irish School System is presented in the report. Some key observations that emerged from this analysis are as follows:

- While there have been some general improvements in the performance of Irish students in international assessments such as TIMSS (Trends in International Mathematics and Science Study) and PISA (the OECD's Programme for International Student Assessment), a consistent finding across national and international tests of attainment is that primary and post-primary students find items assessing higher-order thinking skills (e.g. Applying knowledge and Problem Solving) particularly difficult – this is true for both mathematics and science.

- Although the % of students taking Higher Level Mathematics at Leaving Certificate has increased significantly (from 16% in 2011 to 28% in 2016) since the introduction of Bonus CAO Points, there are serious concerns about the 'mathematical under-preparedness' of students entering third level and about the lack of basic skills of some students sitting the Higher Level paper.

- The majority of teachers of Science subjects have a Biology qualification (more than three times as many as for Physics), as evidenced by Teaching Council Registration data.

- There is a strong imbalance in the number of students studying Leaving Certificate Biology compared to the other Science subjects (>4x number taking Chemistry; >5x number taking Physics)

- There are significant gender differences in the selection of Science subjects at Leaving Certificate, with the ratio of male students to female students greater than 3:1 for Physics and approximately 2:3 for Biology

- Women are greatly under-represented in the STEM workforce in Ireland. The Central Statistics Office (CSO) estimates that fewer than 25% of approximately 120,000 people working in jobs that use STEM skills but are women. While recognizing that this problem may have a number of causes, it is clear that a major contributory factor is the selection of subjects and Third Level programmes by young women at post-primary level. One key barrier in this regard arises from the fact that, while parents are the main influencers when it comes to advising their daughters on how to define educational and career paths, they generally lack information about career options.

- A particularly impressive aspect of STEM Education in Ireland is the highly active informal STEM education sector. This sector, which operates outside the formal curricular teaching in schools, includes initiatives such as the BT Young Scientist and Technology Exhibition (BTYSTE), SciFest, CoderDojo, Coolest Projects, RDS STEM Learning, LearnStorm and Smart Futures. There is a concern, however, that the benefits of these initiatives are not fully realised under present conditions and that excellent work by students, and the potential for much greater engagement with STEM activities, may be under-leveraged because it is not integrated into the curriculum or assessment instruments.

- Without an effective national policy on STEM education to secure and sustain a sufficient supply of high-quality scientists, engineers, technologists and mathematicians, there are serious concerns that Ireland might lose economic competitiveness and fail to realise its potential as a nation. For example, according to the Expert Group on Future Skills Needs (EGFSN), over the next six years Ireland will be challenged to fill an over 40,000 projected job opportunities requiring high-level skills in Information and Communication Technology (ICT).

- A significant problem with 'out of field' Mathematics teachers at Junior Cycle level has been largely corrected by DES-supported initiatives in recent years. ('Out-of-field' teachers are teachers who hold no recognised teaching qualification in the subject being taught.) Similar initiatives will be required in Physics and Chemistry, for example, in order to ensure that all STEM teaching in secondary schools is delivered by qualified STEM teachers (as defined by the Teaching Council).

Each of the five Terms of Reference is analysed in detail in the Report, key issues are highlighted in each case, and a set of Proposed Actions is presented to address these issues. The report concludes with a set of General Recommendations. Although it is not appropriate to repeat the full set of Proposed Actions and General Recommendations in this Executive Summary, it is useful to provide representative examples here, without prioritisation, as they are indicative of the overall thrust of the Report:

- The development of specialist STEM teachers ('STEM Champions') should be encouraged in primary schools. Such specialists would work with colleagues to disseminate insights and best practice in STEM Education. A 'STEM Champion' should hold a recognised postgraduate qualification (e.g. in Mathematics Education, Science Education, Technology Education, STEM Education).

- All STEM teaching in post-primary schools should be delivered by qualified STEM teachers, and the imbalance in the proportions of teachers qualified in biology, physics and chemistry should be addressed as a matter of urgency.

- Working with the Teaching Council, all stakeholders should ensure that a comprehensive suite of STEM CPD programmes is available to post-primary teachers as part of their professional learning requirements under the forthcoming Teaching Council Framework for Continuous Professional Learning.

- Measures should be put in place to support the implementation of inquiry-based learning (IBL) as part of the revised curricula for STEM subjects. Innovative assessment that aligns with inquiry-based teaching and learning should be developed.

- Support the introduction of digital technology to facilitate international collaboration in STEM subjects between schools, and between schools and research facilities (e.g. remote telescopes, remote laboratories).

- Develop a suite of 'Technology-Enhanced Learning' (TEL) CPD programmes in STEM disciplines for teachers at primary and post-primary levels.

- Ambitious targets and a sustained, multi-faceted action plan to address the gender imbalance in specific STEM disciplines should be established and implemented as a matter of urgency.

- The career possibilities for students who follow a STEM career path should be highlighted not only to students but also to parents.
- Produce an integrated National STEM Education Policy Statement with input from, and relevance to, all stakeholders across the continuum of education in Ireland (primary, secondary and third level).
- Introduce computer science (including coding) as a Leaving Certificate curriculum subject. This is critical to address the ICT skills deficit in Ireland.
- Establish the STEM 2020 Partnership - a fixed-duration, public-private (enterprise-exchequer) partnership to create a fund to support a prioritised set of agreed, specific initiatives consistent with the recommendations of this report. This would entail pooling of resources from enterprise partners, philanthropy and crowdsourcing with resource-matching by the exchequer (DES, DJEI, SFI) over a five-year period. A fund of €8M per annum for five years, equally subscribed from public and private interests, is envisaged.
- Establish STEM education research as a national research priority with multi-annual, sustained funding commitment through SFI.

Our aim as a nation should be to ensure that STEM education in Ireland is of the highest international quality. Our review has identified both positive elements and serious deficits in the current STEM landscape in Ireland. The positive features are to be found in both formal (e.g. curricular reform) and informal education developments, but many are taking place in an uncoordinated, independent fashion, rather than as part of an overarching, coherent, cooperative strategy. On the deficit side, the highest-level concerns are the absence of a clearly-articulated STEM education policy and the levels of performance attained (in international assessments, for example). The overall levels of performance and engagement in STEM subjects are not good enough if we aim to provide the best for our nation's children, and if we wish to sustain our economic ambitions for the future. A step-change in STEM performance and outcomes is required throughout the educational system if we are to move our STEM education performance up to the highest levels.
The focus of this report has been to identify pathways to achieving that step-change so that, through implementation of our Proposed Actions and General Recommendations, the quality of STEM Education in Ireland will be enhanced considerably and sustainably.

Achieving this aim will require commitment, investment and early action, together with partners across all the primary stakeholders in both the formal and the informal learning sectors. It is clear that the most effective approach will involve a coalition of committed partners across government departments (especially DES) and agencies, the enterprise sector, professional and learned societies, teachers and communities. In particular, the enterprise sector has an important role to play in supporting Government in ensuring the provision of a high-quality graduate output aligned with national economic needs.

The STEM Education Review Group proposes the following Vision statement as an overarching guide to the actions to be implemented following publication and evaluation of this report:

A Vision for STEM Education in Ireland
Our vision is to provide students in Ireland with a STEM education experience of the highest international quality; this provision should underpin high levels of student engagement, enjoyment, and excellent performance in STEM disciplines.

CHAPTER 1

Overview

Introduction

The STEM (Science, Technology, Engineering and Mathematics) Education Review Group (STEMERG Composition, Appendix I) was established in November 2013 with a view to carrying out a comprehensive review of STEM education in Ireland and to making a set of recommendations that would address identifiable deficits and enhance the quality of our STEM education system significantly. The focus of the Review was restricted to primary and post-primary education.

For many reasons, it is important that STEM education in Ireland is of the highest international quality. These reasons include the intrinsic educational benefits, the direct link to economic competitiveness and the need for well-informed citizens in democratic decision-making:

- Stimulating curiosity and fostering a sense of wonder are essential elements of educating our students from the earliest years. Science and Mathematics provide answers to the fundamental questions of nature and enable us to understand the world around us. The STEM disciplines enable us to understand, measure, design and advance our physical world.
- Expertise in STEM subjects is necessary to drive our economic competitiveness and to provide the foundations for future prosperity. Knowledge-based economies, such as Ireland's, are particularly dependent on the quality and number of STEM graduates.
- Modern democracies need scientifically literate citizens in order to make well-informed decisions regarding major global issues such as climate change, sustainability, energy, and food security.

The agreed Terms of Reference (TOR) for the review were as follows:

TOR-1 The preparation of teachers (Initial Teacher Education; ITE) at Primary and Post-Primary Level for STEM education.

TOR-2 The best methods of supporting the current cohort of STEM Teachers within the system, with a particular focus on Continuing Professional Development (CPD) programmes.

TOR-3 The introduction of new teaching and learning modalities that would enhance STEM education in our schools and for which there is a strong evidence base (e.g. inquiry-based learning and problem-based learning approaches; new assessment modalities)

TOR-4 The use of technology to enhance learning (especially digital and/or on-line approaches).

TOR-5 The promotion of STEM careers and the identification of methods to enhance the engagement of students in STEM subjects.

The emphasis on STEM teachers and teaching in the Terms of Reference is entirely appropriate. As the 2010 McKinsey Report, *How the world's most improved school systems keep getting better* (Mourshed, Chijioke & Barber, 2010), insists, 'great/excellent' status is largely achieved on the back of the quality of a school system's teachers, or, as it is captured in the 2007 McKinsey Report, *How the world's best-performing school systems come out on top* (Barber & Mourshed, 2007), "the quality of an education system cannot exceed the quality of its teachers" (p.15). The other Terms of Reference focus on enhancing the student learning experience in STEM subjects, through the introduction of proven innovations in teaching, learning and technology, and on student engagement with STEM subjects with a particular focus on future careers.

Although STEM refers to Science, Technology, Engineering and Mathematics, the use of the acronym has come to signify more than a simple list of related disciplines. Effective STEM education helps the learner to develop the disciplinary knowledge (e.g. Biology, Physics, Chemistry, Mathematics, Engineering, Technology), the skills (e.g. problem-solving, modelling, design, IT skills), and habits of mind (e.g. inquiry, evidence-based reasoning, logical thinking) associated with STEM disciplines. In this report, Mathematics is viewed as a fundamental discipline since it underpins all the other STEM disciplines.

The STEM landscape in Ireland

STEM Curricula in the Irish Education System

Sector	Area	Subject
	Science	Science
Primary	Technology	Although not a curriculum subject per se, the use of ICT, as a means of enhancing teaching and learning, is promoted across the primary school curriculum
	Mathematics	Mathematics
Junior Cycle	Science	Science
	Technology	Technology, Material Technology (Wood), Metalwork
	Engineering	Technical Graphics
	Mathematics	Mathematics
Senior Cycle	Science	Biology, Chemistry, Physics, Agricultural Science, Physics & Chemistry
	Technology	Technology, Design and Communication Graphics
	Engineering	Engineering, Construction Studies
	Mathematics	Mathematics, Applied Mathematics

***Table 1** STEM subjects*

Primary Schools

The Primary School Mathematics Curriculum (PSMC) for Junior Infants to Sixth Class was introduced in 1999 (Government of Ireland, 1999a). It comprises five strands: Number; Algebra; Shape and Space; Measures; and Data. Spanning the content are skills that pupils should develop, such as implementing, problem solving, communicating, and reasoning. In July 2011, the Department of Education and Skills launched a strategy document, *Literacy and numeracy for learning and life: The national strategy to improve literacy and numeracy among children and young people 2011- 2020* (DES, 2011). In this document, a range of measures designed to raise standards in literacy and numeracy, from early childhood to the end of second-level education, is outlined. These include increased allocation of teaching time to mathematics in schools and greater emphasis on mathematics in the initial education of teachers. The PSMC (for 3 – 8 year olds) is currently being redeveloped and is expected to be available in 2017.

Science has been a compulsory subject for all primary school pupils since 1999 (Government of Ireland, 1999b). In the Primary School Science Curriculum (PSSC), emphasis is placed on the development of scientific content knowledge (in biology, physics and chemistry) and on the development of scientific skills. There are four content strands in the PSSC: Living Things, Energy and Forces, Materials, and Environmental Awareness and Care. Although they are included in the PSSC, some elements of Earth Science are included in the Primary School Geography Curriculum (PSGC) (Government of Ireland, 1999c).

While acknowledging that some excellent science teaching is taking place in primary schools, concerns have been expressed (Childs, 2014) about Primary Science with regard to:

- the amount of time allocated to Science
- the limited Science background of Primary teachers
- the amount of time spent on Science in the initial education (ITE) of Primary teachers
- the lack of appropriate Science-based CPD for Primary teachers.[1]

Post-primary schools
Science at post-primary level comprises Junior Certificate Science (3 years duration) and Leaving Certificate Science subjects (2 years duration).

Junior Cycle
The Junior Cycle Science curriculum was introduced in its present form in 2003 and included the assessment of practical work (worth 35%) for the first time (Government of Ireland, 2003). It is a general science course involving Biology, Chemistry, and Physics and is offered at two levels, Higher and Ordinary. Although the course is not compulsory, it is taken by c. 90% of students, with a slight gender imbalance in favour of boys. All Junior Cycle students take mathematics at Higher, Ordinary or Foundation level. A phased replacement of the traditional syllabus by the application-oriented 'Project Maths' specifications[2] began in September 2008, and was fully implemented in 2013 (Government of Ireland, 2012).

Most teachers of Junior Cycle Science have a Biology qualification, as evidenced by their Teaching Council Registration data (this data are presented later in this chapter). Childs (2014) has articulated concerns that this may have led to increased emphasis on Biology in Junior Certificate Science to the detriment of Chemistry and Physics. Furthermore, this factor is likely to contribute to the dominance of Biology as a subject choice for students choosing a Science subject for the Leaving Certificate. There are also concerns amongst Science teachers about practical work and its assessment (Childs, 2014). Whilst teachers welcome the increased emphasis on practical work, and the assessment of practical work, they argue that this has led to increased workload in terms of planning, preparation of equipment and general laboratory

1 A pilot phase of CPD for primary teachers ***RDS STEM Learning***, supported by RDS and Dublin City University took place during 2012-2014. This is due to be expanded significantly through a partnership between the RDS and SFI.

2 In 2011 the NCCA moved away from the use of the term *syllabus* in favour of the term *specification* which embraces both the course and the means of assessment.

maintenance, and may result in less time for developing the conceptual ideas underpinning the practical work (Eivers, Shiel and Cunningham, 2008). Given the increased emphasis on practical work, the lack of technical assistance is often cited as a concern.

There are four technology subjects offered at Junior Cycle. They are all offered at Higher Level and Ordinary Level. With the exception of Technical Graphics, the technology subjects are assessed by a written paper and a project-based component. Technical graphics is assessed by means of a written examination paper only.

- Materials Technology (Wood): tasks that require the use of practical problem-solving skills and the application of scientific and technological knowledge.
- Metalwork: (i) techniques and design, which incorporates all of the practical work (ii) Materials and technology which is the related technical and technological principals and theory.
- Technical Graphics: spatial problems and the graphical communication of spatial ideas and solutions.
- Technology: design process to devise solutions to problems in a number of tasks.

Senior Cycle

There are five Leaving Certificate Science subjects: Biology, Chemistry, Physics, Physics & Chemistry, and Agricultural Science. Each of these subjects is offered at two levels, Higher and Ordinary. There is a strong imbalance in the numbers of students studying Leaving Certificate Biology compared to the other Science subjects as can be seen from Fig. 1 below. For example, the data for the 2014 Leaving Certificate yields the following percentages:

Subject	Percentage of total
Agricultural Science	14%
Biology	61%
Chemistry	16%
Physics	13%
Physics & Chemistry	<1%

Table 2 *Percentage of students taking STEM subjects for 2014 Leaving Certificate.*

Reprinted from State Examinations Statistics by State Examinations Commission (SEC). Retrieved from ***https://www.examinations.ie/index.php?l=en&mc=st&sc=r14***

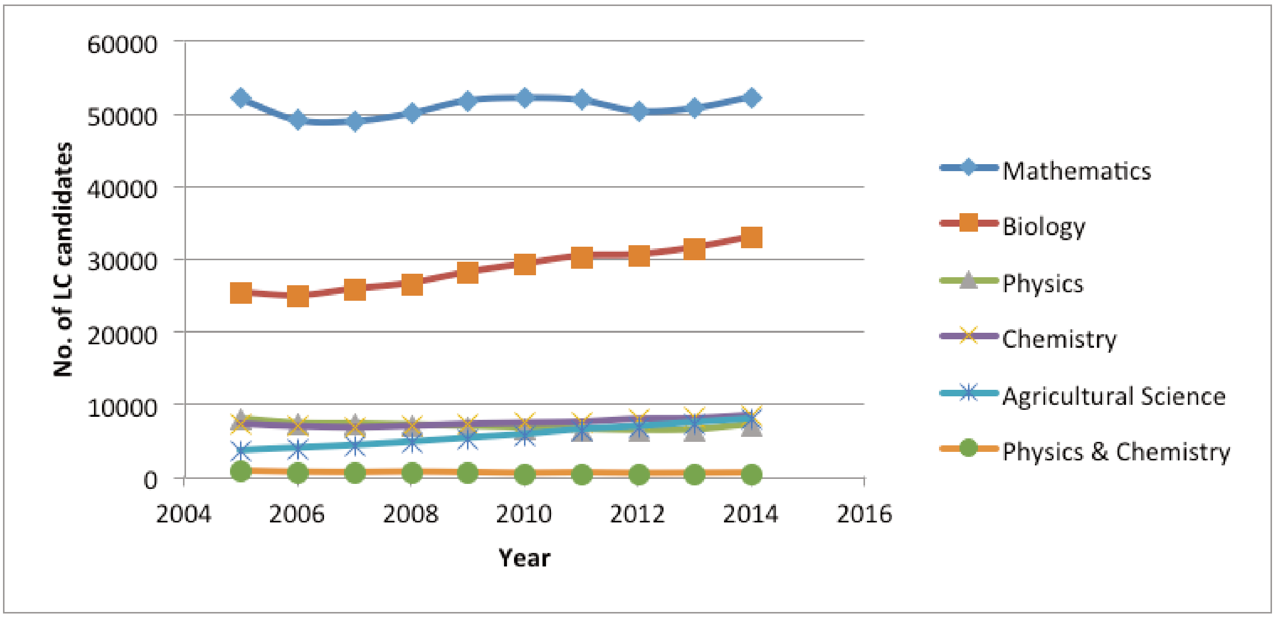

Figure 1 *Trends in numbers of candidates taking selected Leaving Certificate subjects.*

Reprinted from State Examinations Statistics by State Examinations Commission (SEC). Retrieved from https://www.examinations.ie/index.php?l=en&mc=st&sc=r14

Moreover, as fig. 1 illustrates, this imbalance in favour of Biology over other Science subjects has been increasing in recent years. Using 2013 Leaving Certificate data, fig. 2 illustrates the gender imbalance in students taking physics and biology. 76% of the total number of students taking Leaving Certificate physics were boys, whereas boys accounted for only 40 % of the total in biology.

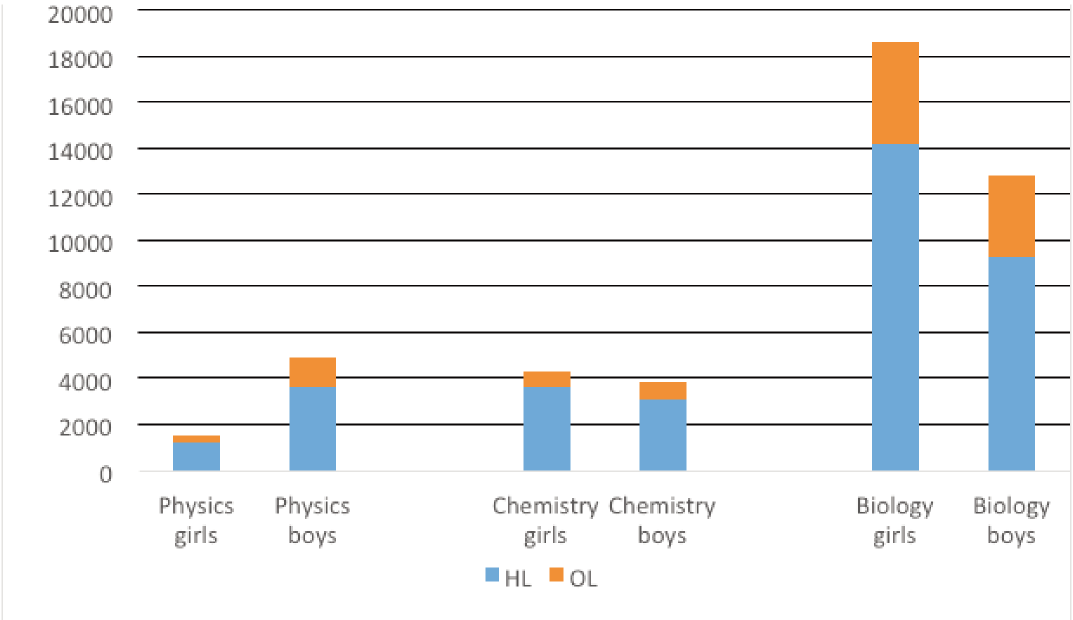

***Figure 2** Numbers sitting physics, chemistry and biology by gender (Leaving Certificate 2013).*

Reprinted from State Examinations Statistics by State Examinations Commission (SEC). Retrieved from https://examinations.ie/index.php?l=en&mc=st&sc=r13

Apart from written questions in examinations, none of the current Leaving Certificate Science syllabi includes assessment of practical work. The Science syllabi, however, do include mandatory experiments that must be written up in laboratory notebooks that must be available for inspection.

There are four Leaving Certificate Technology subjects: Engineering, Construction Studies, Technology, and Design and Computer Graphics. Each of these subjects is offered at two levels, Higher and Ordinary. As well as there being very low total numbers of students taking these subjects, there is a strong gender imbalance as can be seen from Fig. 3 below. For example, the data for the 2014 Leaving Certificate yields the following percentages:

Subject	% of total	Of those taking each subject:	
		% Girls	% Boys
Engineering	9.6	5.3	94.7
Construction studies	15.6	7.3	92.7
Technology	2.0	25.9	74.1
Design and Communication Graphics	9.9	10.9	89.1

***Table 3** Numbers of candidates taking Leaving Certificate Technology subjects.*

Reprinted from State Examinations Statistics by State Examinations Commission (SEC). Retrieved from https://www.examinations.ie

Although Mathematics is not compulsory, virtually all Leaving Certificate students take Mathematics at some level e.g. 97% of LC students in 2014 took the subject. Only a small (albeit increasing) proportion of these students takes Higher Level Mathematics. This set of conditions and other factors contribute to the small number of students who qualify to pursue STEM degree programmes in Higher Education (HE). The impact is particularly felt in Physics, Mathematics and Engineering disciplines with low numbers entering HE and subsequently qualifying in those STEM disciplines.

The proportion of the students taking the LC (H) Mathematics examination has increased markedly in recent years:

Year	Percentage of students taking HL mathematics
2011	16%
2012	22%
2013	26%
2014	27%

Table 4 *Percentage of students taking LC (HL) mathematics: 2011-2014.*

Two factors (Bonus CAO Points and the Project Maths initiative) are likely to have played a significant role in this increase, although their relative impact is difficult to estimate. The award of 25 CAO points for achieving a minimum of grade D in the Higher-Level Mathematics examination in the Leaving Certificate has certainly enticed students wishing to maximise their overall CAO score. In a report to the Department of Education and Skills in 2013, the Irish Maths Teachers Association (IMTA) emphasised the popularity of the new 'Project Maths' approach with students, indicating that students enjoyed the teaching methods and the use of more real-life application contexts (IMTA, 2013).

The backwash effect of the bonus points incentive together with the introduction of the new Project Maths curriculum at Junior Cycle also appears to be having a positive impact on the numbers taking the higher-level option in the Junior Certificate examination. The proportion now stands at 54% (2014) compared to 43% in 2008. Given the underpinning role that Mathematics plays across STEM disciplines, these are positive developments. Nevertheless, comments from the HE sector regularly raise concerns about 'mathematical under-preparedness' for third level education. Such concerns have led to the development of Mathematics Learner Support (MLS) provisions and the establishment of Maths Learning Centres that help students to make the transition from second to third level successfully and to improve mathematics and STEM outcomes for students throughout their undergraduate career (O'Sullivan, Mac an Bháird, Fitzmaurice & Ní Fhloinn, 2014).

OVERVIEW

New post-primary STEM Curricula
New curricula in Junior Certificate and Leaving Certificate Mathematics were introduced on a phased basis between 2008 and 2013. These are commonly referred to as 'Project Maths'. New curricula for Junior Certificate Science and Leaving Certificate Biology, Chemistry and Physics are awaiting implementation, and a new specification in Agricultural science is in development. The new STEM curricula emphasise the development of skills as well as discipline knowledge and understanding. The new subject specifications are presented as learning outcomes that describe what students should be able to do rather than what they should know. The specifications demonstrate clear progression of learning through post primary education as students consolidate and deepen their knowledge and understanding, and develop skills. Emphasis is placed on the application of discipline knowledge in real-world contexts. The implementation of these new curricula will result in the introduction of practical assessment in Leaving Certificate physics, chemistry and biology for the first time.

Performance and quality
The 2010 McKinsey Report, *How the world's most improved school systems keep getting better* (Mourshed, et al., 2010) ranks Ireland's school system in the category 'good – great' based on an aggregate score across several indicators of academic performance at primary and post-primary levels. In order to match our ambitions for economic and societal development, our aspiration as a nation should be ranked with the high performing nations in the 'great – excellent' category.

The situation is far from 'great' if we consider STEM subjects. Our performance has been consistently average, hovering just above, or below in some instances, according to a series of reports on the TIMSS (Trends in International Mathematics and Science Study) and PISA (the OECD's Programme for International Student Assessment) studies. Ireland's performance in Mathematics has been decidedly average, moving to significantly above average in PISA 2012, and has generally been just above average in Science (Perkins, Shiel, Cosgrove, Merriman, & Moran, 2013).

While some of these trends are welcome, a consistent finding across national and international tests of attainment is that primary and post-primary students find items assessing higher-order thinking skills (e.g. Applying Knowledge and Problem Solving) particularly difficult – this is true for both mathematics and science. Another concern is that there are relatively few of our primary and post-primary students performing at the 'advanced level of proficiency' in mathematics (Mullis, Martin, Foy & Aurora, 2012; Perkins et al., 2013). A number of reports draw attention to low levels of ICT usage by students in primary schools in Ireland. National studies highlight that, where ICT is used, it is mainly for low-level activities such as word processing, internet searches and playing computer games. Limited use is made of ICT in the development of higher-order thinking skills, creative or collaborative skills, independent working skills, or communication skills (e.g. DES, 2008; Eivers et al., 2010).

These levels of performance in STEM subjects are not good enough if we aim to provide the best for our nation's children and if we wish to sustain our economic ambitions for the future. A step-change in STEM performance and outcomes is required throughout the educational system if we are to move our STEM education performance into the highest levels.

STEM teachers

Established in March 2006, the Teaching Council of Ireland regulates the teaching profession in Ireland and the vast majority of teachers are registered with the Council. Details of the registration process and criteria for both Primary and Post-Primary teachers are detailed in Appendix II.

For a number of reasons, it is difficult to establish the exact numbers of teachers (post-primary) engaged with STEM subjects in schools. For example, the number of registered teachers at any given time comprises teachers who are in permanent positions of employment, those who are in temporary and /or part-time positions, and those who have no post at all. Table 4 below, however, gives a useful snapshot that can be used for indicative purposes. The data do not give an accurate picture of how teachers are deployed across the school system. Where it appears, the subject in parenthesis in any row is the corresponding subject that the teacher is registered to teach at Junior Cycle. Taking only those subjects that allow teaching of Science at Junior Cycle level, the data in the table show that more than half of Science teachers are qualified in Biology while fewer than one fifth are qualified in Physics.

Subject	Number of teachers currently registered on the basis of qualifications in that subject (2014)
Agricultural Science	729
Applied Mathematics	420
Biology (Science)	3,694
Chemistry (Science)	2,305
Computer Studies (IT or ICT)	580
Construction Studies (Technology & M.T.W)	1,352
DCG (Technical Graphics)	1,215
Engineering (Metalwork/Technology)	769
Mathematics	5,171
Physics (Science)	1,197
Physics and Chemistry (Science)	24
Technology	159

***Table 5** Number of STEM teachers currently registered with Teaching Council*

Source: Teaching Council of Ireland (personal communication)
Note: Where included, a curricular subject in parentheses indicates that the teacher is also registered to teach that subject at Junior Cycle.

Out-of-field teachers

The teaching of specific subjects in secondary schools by teachers who hold no recognised teaching qualification in that subject is clearly not desirable. These teachers are referred to as 'out-of-field' teachers (Ingersoll, 2002). The practice is not unique to Ireland and is common place internationally as shown by comparative statistics in a report on this topic (Ní Ríordáin and Hannigan, 2009). However, the practice impacts disproportionately on Junior Cycle Mathematics students as very few qualified Mathematics teachers are deployed in the early years of Junior Cycle as the report shows. Based on their survey, Ní Ríordáin and Hannigan estimated that 48% of teachers of mathematics were out-of-field.

This issue has been addressed very effectively through the provision of a special programme to up-skill and qualify out-of-field teachers of Mathematics who are currently employed in the schools. The Professional Diploma in Mathematics for Teaching, a government-funded 2-year part-time blended learning programme, has been offered since September 2012 by a consortium of HEIs led by EPI*STEM (formerly NCE-MSTL) at the University of Limerick. Four cohorts of teachers have been approved to date; 288 members of cohort 1 graduated in January 2015; cohort 2 (295 teachers) and cohort 3 (230 teachers) are engaged in the programme and cohort 4 (150 teachers) are currently participating in the programme. Successful graduates are deemed by the Teaching Council to have met their requirements for mathematics teaching.

GENERAL ISSUES

Policy context

Ireland does not have a STEM education policy per se. *Innovation 2020*, which was published in December 2015, is Ireland's Strategy for Research and Development, Science and Technology. Chapter 3 of *Innovation 2020* deals with 'Education for Innovation' and states the following: '*The education of Ireland's young people must be underpinned by a highly valued and highly skilled teaching profession. A unified continuous professional development strategy will ensure consistent teaching and learning in the various science subjects. The ongoing work of the Teaching Council in developing a National Framework for Teachers' Learning, and the Report of the STEM Education Review Group will inform developments in this area.*'

While highlighting the need for a high-performing STEM Education system in Ireland, it is disappointing that *Innovation 2020* does not identify the absence of a national policy or strategy in this context and does not call for its establishment. Without an effective strategy for STEM education to secure and sustain a sufficient supply of high-quality scientists, engineers, technologists and mathematicians, there are serious concerns that Ireland could lose economic competitiveness and fail to realise its potential as a nation. For example, according to an expert group, over the next six years Ireland will be challenged to fill an estimated 44,500 jobs requiring high-level skills in Information and Communication Technology (ICT) (Expert Group on Future Skills Needs (EGFSN), 2013). The HEA has warned that graduate output may fall behind demand in the economy in the period to 2020 (HEA, 2014). The authors of this report point out that, if current enrolment projections are realised over the period 2014 – 2020, projected graduate output will fall short of labour market needs by 20% in a *Recovery by 2020 scenario*. In this context, it is recognised that the ICT Skills Action Plan (DES/DJEI 2014) makes important recommendations that both overlap and complement the content and recommendations of this report.

The gender gap in the Irish STEM-related workforce

Women are greatly under-represented in the STEM workforce in Ireland. The Central Statistics Office (CSO) estimates that there are approximately 117,800 people working in Ireland in jobs that use STEM skills but fewer than 25% of these workers are women This represents gross under-engagement with a talent pool comprising half the country's population. The Accenture report, *Powering economic growth: Attracting more young women into science and technology* (Accenture, 2014), which was based on a survey of 1000 female secondary school students, young women, parents and school-teachers, identifies key barriers operating in the post-primary system as follows:

- Negative stereotypes exist that STEM subjects and careers are more suitable for boys.
- Although parents are the main influencers when it comes to advising their daughters on how to define educational and career paths, they lack information about career options.
- There is fragmented information available about STEM careers, making it difficult for students and their parents to evaluate options.
- A disconnect exists between industry's skills needs and students' subject choices for their Leaving Certificate Examinations.

Informal STEM education initiatives

Ireland can boast a very active and extensive informal STEM education sector. The informal sector includes contributions from business and industry (both directly and through their representative associations), learned societies, professional organisations, foundations, social enterprises, science centres, teachers, volunteers and government agencies. Activities include local school projects, visits, exhibitions, Science festivals, Science week, Maths Week, and competitions local, regional, national, and international. As part of this Review, we have endeavoured to capture a representative sample of the broad range of such activities taking place in Ireland (Appendix III: Audit of STEM Education Activities). Many of these projects are supported by Science Foundation Ireland through partnerships and/or funding.

Numerous informal, extra-curricular STEM initiatives that emphasise inquiry-based learning, skills development, curiosity-inspired projects and a focus on STEM careers are active across Ireland and are having a substantial impact. Figure 3 gives some examples of such initiatives. There is a growing appreciation of the significance of the contribution of the informal sector to the national STEM education agenda, allied with a concern that its benefits and potential are not fully realised under present conditions. For example, many initiatives are not uniformly distributed nationally (leading to advantages for students in large urban areas, for example) while others are teacher-dependent or dependent on the local engagement with enterprise. Similarly, excellent work by students and the potential for much greater engagement with STEM activities is under-leveraged because it appears (to students, teachers and parents) to be under-valued by the education system because it is not integrated into the curriculum or assessment instruments.

OVERVIEW

The BT Young Scientist and Technology Exhibition (BTYSTE)
The BT Young Scientist and Technology Exhibition (BTYSTE) began in 1963 and for decades has enabled second level students to develop their STEM skills by devising and carrying out projects. The annual showcase attracts major public attention and several winners have gone on to represent Ireland internationally and to forge careers in STEM areas. 2016 saw over 2,000 projects being entered, 550 projects selected and around 60,000 visitors at the exhibition in the RDS. Since its inception, the cumulative impact of the BTYSTE has been immense and it is a striking model of the value of inquiry-based learning.
SciFest
SciFest hosts one-day science fairs for second-level students at local, regional, and national levels that encourage students to prepare and showcase inquiry-based projects. In 2016, more than 8,000 students from 256 schools presented more than 3,500 projects. At the regional level, SciFest@College takes place at Institutes of Technology (and DCU) and winning projects move on to a national SciFest science fair supported by Science Foundation Ireland. Overall winners represent Ireland in an international competition.
CoderDojo
CoderDojo started in Cork in 2011 and is now a global volunteer-led community of free programming clubs for young people aged between 7 and 17. Young people attending a Dojo (typically weekly) learn how to code and create with software and hardware. The emphasis is on peer learning, mentor-led and self-led learning and having fun with technology in a social environment. There are now more than 1,090 Dojos in 63 countries. Within the CoderDojo community, some dedicated CoderDojo sessions have been established to encourage the participation of girls.
Coolest Projects
The **Coolest Projects** Awards is the annual showcase event for projects created by young people in CoderDojo. It has grown from 15 projects in 2011 to more than 700 in 2016. The awards particularly reward creativity and project-based learning, and they encourage young coders to share their achievements with STEM and to gain confidence in their presentation skills.
MATHletes
The **MATHletes** Challenge (now called **Learnstorm**) encourages students from 4th class in primary school to 5th year in secondary school to engage with maths. In 2015 the free competition saw more than 13,000 students spend more than three million minutes competing on the Khan Academy's free online maths learning platform, completing more than 4.5 million problems and mastering more than two million maths skills. The participation rate was four times that of its debut year in 2014.

Figure 3 Examples of informal STEM education initiatives

Smart Futures
Smart Futures promotes STEM careers to second-level students, parents, guidance counsellors, and teachers in Ireland, highlighting opportunities in sectors such as pharma chemical, medical devices, information and communications technology (ICT) and energy. Managed by Science Foundation Ireland (SFI) in partnership with Engineers Ireland, the Smart Futures programme aims to provide national coordination of STEM careers outreach activities. Events and initiatives in this government-industry partnership include school visits by science researchers and engineers, a Transition Year Work Experience programme, a Video Series and a blog that profiles people working in STEM to give an insight about their work and experience. Over the past two years, Smart Futures has engaged with over 54,000 secondary school students through these initiatives.
RDS STEM Learning
RDS STEM Learning is an interactive, peer-to-peer continuous professional development programme that seeks to develop teaching approaches and conceptual knowledge of science at the primary school level. A pilot phase supported by RDS and Dublin City University started in 2012 and engaged with 50 primary school teachers in Ireland (12 facilitators and 38 teachers). It introduced innovative techniques to schools, integrating open-ended, problem-solving activity within the classroom, allowing students to explore the primary science curriculum through child-led inquiry. An independent review of the initiative found that it greatly helped students' thinking skills and creativity in science, and more than 90 per cent of respondents surveyed said it had an impact on exploring children's ideas of science. The RDS-DCU CPD initiative will now scale up through a partnership with Science Foundation Ireland, with plans to have a further 52 facilitators by 2017.
The Intel Mini Scientist Exhibition
The Intel Mini Scientist Exhibition is a programme for Primary school students in which they develop science related projects that are exhibited at fairs at their own schools. Winning projects progress to Mini Scientist Regional Finals with selected projects continuing on to the Grand Final. The competition, which is open to 4th, 5th and 6th class students, supports the Primary Science curriculum and promotes an inquiry-based approach to practical learning in the area of science. In 2014, over 5,500 students participated in the Mini Scientist programme.

Figure 3 (continued)

Challenges for the teaching profession

Perhaps the most challenging dilemma facing teachers today is the extent of the change in their professional lives. This is particularly true for STEM teachers. Recent developments across the education continuum in Ireland see a move away from the explicit specification of content towards a more generic, skill-based approach to discipline knowledge. There is greater emphasis placed on the centrality of the learner, and greater requirements for teachers to use their professional judgement in developing the curriculum in school. The forms of pedagogy associated with this teaching and learning approach encourage the development of deep learning in students. But they also place new and increased demands on teachers. As well as having more responsibility for what is taught, teachers are increasingly expected to teach knowledge and understanding in STEM disciplines in such a way that students develop the so-called 21st Century skills identified as being critical at each stage of the education continuum (Binkley et al., 2012). (See Appendix IV: Key skills identified at each stage of the Irish Education continuum). To negotiate this change successfully, teachers will require a programme of extensive and sustained CPD throughout their professional life, not just in response to curriculum change.

The crisis in public finances in the period from 2008 has impacted heavily on education at all levels. One particular consequence is the so-called 'casualisation' of the teaching profession and that is having a severe, negative impact on provision at post-primary level. It is estimated that ca.35% of all teachers in the post-primary schools have less than full-time contracts of employment (Ward, 2014). Although the impacts are not unique to STEM subjects, there are concerns that STEM teaching and the associated student performance suffer in this context because STEM teachers need to build confidence in their knowledge and skills and students need continuity and confidence in their teachers.

PROCESS OF CONSULTATION AND STRUCTURE OF REPORT

Submissions and consultation

In addition to the significant contributions of all members of STEMERG, this report has been developed with the input of a broad range of stakeholders. While researching and developing the report, members of the public, academic and educational institutions, and professionals in the education sector and their representative bodies were encouraged to submit their thoughts and considerations on STEM education in Ireland.

A major public consultation event was held at the Royal Irish Academy (RIA) on April 17th, 2014. A summary of that event and its outputs is available in Appendix V. The presentations and discussions at the RIA event provided important and stimulating reference points for our work. They highlighted key issues that need to be addressed regarding STEM education in Ireland and the environment in which changes can be made.

In addition to the public consultation event, a number of written submissions were received from stakeholder bodies. Where necessary or convenient, these were supplemented with face-to-face engagements with representatives of the stakeholder bodies.

Structure of report

This report comprises seven main sections:

- Chapter 1 - Introductory Overview Chapter (p.12)
- Chapter 2 – 6 – corresponding with each of the five TORs
- Chapter 7 – Conclusions, General Recommendations and Combined Report Outcomes
- References and Appendices

CHAPTERS 2-6

TERM OF REFERENCE 1:

PREPARATION OF TEACHERS (AT PRIMARY AND POST-PRIMARY LEVEL) FOR STEM EDUCATION IN IRELAND

Introduction

The quality of teaching of STEM subjects in schools has a direct bearing on the quality of learner experience and achievement. Thus, any approach that aims to improve STEM education in our schools must treat STEM teacher education as a key priority.

The importance of initial teacher education (ITE) in STEM lies in challenging and deepening student teachers' beliefs about the learning process, in developing their understanding of the nature of the STEM subjects and familiarizing them with a range of teaching approaches. Teacher knowledge is usually viewed as having three strands: subject matter knowledge (SMK), pedagogical knowledge (PK) and pedagogical content knowledge (PCK) (Shulman, 1987). SMK concerns knowledge of content (e.g., knowledge of mathematical or scientific concepts, mathematical or scientific reasoning etc.). PK relates to knowledge of pedagogy and is generally subject independent (e.g. sociological or psychological aspects of education). PCK is the interplay between content and pedagogy, that is, the link between knowing something and facilitating others to learn it. It is expected that, as pre-service teachers progress through their preparatory programmes, these different forms of knowledge become more tightly interconnected.

This Term of Reference looks at STEM engagement at an earlier stage, when teachers are preparing to enter primary or post-primary service. Measures taken at this level of ITE will build STEM capacity in education in Ireland in the long term.

Current practice

ITE: primary school teachers

There are two routes to registration as a primary school teacher in Ireland: the concurrent route, which involves completing an undergraduate degree course in primary ITE, and the consecutive route, which involves completing an undergraduate degree and a postgraduate programme of ITE.

In both entry routes, pre-service teachers are expected to engage in Foundation Studies, Professional Studies and School Placement (Teaching Council, 2011a). As part of professional studies, students begin to develop their PCK of all subjects of the Primary School Curriculum, including STEM subjects. Furthermore the courses are directed towards pupils in classes from Junior Infants to Sixth class.

Essential Leaving Cert grades to qualify for ITE are a Grade C3 in Higher Level in Irish, Grade C3 Ordinary Level or D3 Higher Level in English and Grade D3 (either Ordinary or Higher Level) in Mathematics. The Teaching Council has provided advice to the DES on Leaving Cert grades for entry into ITE programmes. This advice is currently under consideration by the DES.

ITE: post-primary school teachers
Similarly, there are two models for post-primary teacher registration. One is a concurrent model of a degree qualification in post-primary ITE, which combines the study of one or more approved curricular subjects along with teacher education studies.

The other is a consecutive approach of first completing an undergraduate degree, which enables the holder to teach at least one approved curricular subject, and then completing a postgraduate programme of ITE geared towards the post-primary age range.

For a more detailed description of routes to registration for primary and post-primary teachers and the minimum grade entry requirements, see Appendix II.

Key issues

At present, a student entering initial primary teacher education needs a minimum of a Grade D3 (at either Ordinary or Higher Level) in Leaving Certificate mathematics. However, the majority of entrants to primary ITE programmes exceed this grade, and only a small minority present with the minimum grade required in mathematics.

While a high level of content knowledge is necessary, it is not sufficient for the effective teaching of mathematics and, in particular, PCK is now recognised as a 'decisive' variable in student achievement in mathematics (Education Committee of the European Mathematical Society, 2012). In addition, one study has suggested that raising the minimum entry requirement in mathematics may not, in itself, yield a significant improvement of teaching (Corcoran, 2008). Nevertheless, the relatively low entry requirements for mathematics (primary teacher education) compared to the entry requirement grades needed for English, and Irish is, at the very least, problematic in the disciplinary prioritisation that it conveys to students. This balance needs to be redressed. Furthermore, greater support needs to be given to increasing discipline knowledge across STEM subjects at both primary and post-primary levels.

Because mathematics underpins all STEM subjects, there is a strong case for targeting improvements in mathematics teaching. Raising the entry levels (for primary teaching) in mathematics in a measured fashion would not only enhance the public and student perception of the importance of mathematics, but it would also ensure a higher baseline of subject knowledge upon which to build during ITE. In this context, it is most important to emphasise that pre-service teachers should be supported in achieving an agreed level of knowledge of mathematics as they undergo ITE.

Government-supported Initiatives have been put in place to address literacy and numeracy during teacher preparation, but the need to augment science education has not been addressed sufficiently, particularly at primary level. The development of specialist courses/modules in science subjects and science education during primary and post-primary ITE would serve to increase the content on offer to pre-service teachers (such courses/modules are already offered in some HEIs).

In general, the low level of knowledge and insight that pre-service teachers possess in the physical sciences is a matter of deep concern. Low percentages of students entering ITE courses have studied Physics or Chemistry for the Leaving Certificate, while a high percentage of students have studied Biology (Murphy and Smith, 2012). Poor scientific content knowledge leads to a lack of confidence in teaching those subjects.

In Ireland, there has been a move in recent years towards the establishment of a general set of standards for teachers which includes the use of ICT in teaching and learning. Highlighting ICT as one of the key national priority areas and a significant aspect of student teachers' developing professional skills, the Teaching Council lists ICT in Teaching and Learning as one of the mandatory elements of ITE (Teaching Council, 2011a). As ICT has the power to be transformative and lead to the design of new learning environments, its use needs to be embedded across course work in ITE.

School placement is an inherent component of all ITE programmes. While it usually takes place in either a primary or post-primary school (depending on the programme of study), some students of post-primary ITE programmes have a practicum in a senior primary setting. However, short placements with STEM-related industries during teacher preparation could also offer important experience and insights into the importance and practical applications of STEM. This would be an opportunity for industry to contribute to developing stronger STEM education in Ireland.

In addition, student primary teachers' confidence and insight in STEM would be enhanced if they were mentored or supervised by teachers/placement tutors with an expertise in STEM.

Proposed Actions

- The ongoing supply of 'qualified STEM teachers' (at post-primary level) should be a particular focus of the Teaching Council in its planned report on teacher supply to the Minister for Education and Skills.
- The development of specialist STEM teachers ('STEM Champions') should be encouraged in primary schools. Such specialists would work with colleagues to disseminate insights and best practice in STEM Education. A 'STEM Champion' should hold a recognised postgraduate qualification (e.g. in Mathematics Education, Science Education, Technology Education, STEM Education). Support should be provided to primary teachers to gain such qualifications.
- All STEM teaching in post-primary schools should be delivered by qualified STEM teachers (as defined by the Teaching Council), and the imbalance in the proportions of teachers qualified in biology, physics and chemistry should be addressed as a matter of urgency (see TOR 2).
- The minimum entry requirements into the B.Ed. degree programme (for primary teachers) should be reviewed as soon as possible with a view to creating greater equity across core subject areas.

- Students of ITE (primary) programmes should undergo an audit of subject-matter knowledge (SMK) in STEM subjects (mathematics and science) over the course of their programme. Self- or peer-evaluation may be helpful in this regard. Supports should be provided to ensure that students address deficits in their knowledge, e.g. mathematics-learning support.
- Offer incentives (e.g. targeted bonus points per STEM subject up to a maximum of two subjects, for example) to Senior Cycle students seeking to enter concurrent STEM Teacher Education degree programmes (for post-primary) generally but especially in mathematics, physics, chemistry and engineering.
- Support all primary teachers (in ITE) in building their subject matter knowledge (SMK) and pedagogical content knowledge (PCK) in science, mathematics and technology as part of a broader professional portfolio of expertise and related activities.
- Require all primary teachers in ITE to pass all STEM-methodology-related subjects (without compensation) in final examinations, where this is not currently the case.
- Include a formal consideration of STEM education during mentoring of student teachers during their primary school placement.
- Support the active engagement of schools with STEM-related industries across a broad range of fronts (e.g. the possibility of optional placements in STEM industries during primary and post-primary teacher preparation phases should be explored).

TERM OF REFERENCE 2:

THE BEST METHODS OF SUPPORTING THE CURRENT COHORT OF STEM TEACHERS WITHIN THE SYSTEM (WITH A PARTICULAR FOCUS ON CONTINUING PROFESSIONAL DEVELOPMENT)

Introduction

Continuing Professional Development (CPD) is aligned with a vision of teachers as lifelong learners. This lifelong learning is necessary in the STEM disciplines, to update and improve both subject knowledge (the 'what' of STEM teaching) and pedagogical knowledge (the 'how' of STEM teaching). A high quality, sustained, coherent, and supportive model of CPD has the potential to incentivise and support teachers throughout their teaching life, and to harness existing and potential links between formal and informal CPD providers. Following a comprehensive consultation process with teachers and other stakeholders, the Teaching Council, the statutory regulator and professional standards body for teachers, has developed a framework for teachers' learning. Having adopted the framework, the council is now embarking on a development process, whereby teachers will explore the framework and trial aspects of it in their particular context. The development process will conclude in 2019 in advance of implementation in 2020.

Current practice

Formal CPD for STEM teachers is usually motivated by imminent changes to the school curriculum. It is available as activities in individual STEM subjects packaged in units, modules or workshops. These opportunities are made available through a number of providers including DES Support Services, Education Centres, Teacher Education Colleges, HEIs, IOTs, Science and Mathematics Education Centres, subject associations, and professional and learned societies (See Appendix III).

Formal CPD is generally targeted at specific pedagogical content knowledge[3] (PCK), such as inquiry-based science learning or assessment. However, apart from a small number of STEM postgraduate diplomas and Master's/PhD programmes in Education (Science/Mathematics), there are very few programmes of STEM education on offer for post-primary teachers. CPD on the revised Junior Cycle Science Specification commenced in 2016. Subject-specific CPD will be provided for other STEM subjects as they are introduced.

There is evidence of best practice from the DES Support Services and others in the practices surrounding CPD for STEM teachers in school-based collaborative work, evidence-based approaches, integration of new material and the use of ICT.

3 The concept of PCK refers to teachers' interpretations and transformations of subject-matter knowledge in the context of facilitating student learning.

The Continuum of Teacher Education framework (Teaching Council, 2011b) offers an excellent, fit-for-purpose vehicle for building STEM teaching capacity in the Irish education system. This framework acknowledges a key role for CPD for all teachers. A particularly insightful tenet of the Teaching Council's continuum is that lifelong learning encompasses formal and informal learning. The potential of informal STEM education for improving student learning and STEM teacher education is recognised, but remains underexploited.

Project Maths initiative and CPD

The Project Maths initiative is a useful case study offering perspectives on CPD generally, but more particularly on CPD in a STEM discipline that underpins all STEM disciplines.

Under this initiative, Mathematics teachers were expected to develop a new mindset, new teaching approaches and new subject knowledge, and to integrate new technologies, including ICT. This large-scale national project was based on a number of significant supports including:

- A national coordinated effort by the DES Project Maths Development Team, NCCA, State Examinations Commission (SEC), schools and others.
- 10 days out-of-school in-service training over three years, together with in-school support provided by the DES Project Maths Development Team.
- Extra voluntary opportunities including evening and weekend sessions and summer schools.
- Production and availability of Teaching and Learning materials on-line.
- Free Professional Diploma in Mathematics for Teaching to upskill 'out- of-field teachers' of mathematics.

Key issues

Ireland offers a variety of informal STEM offerings and activities for the public, schools and teachers. They include headline events such as the BT Young Scientist and Technology Exhibition, SciFest, and FÉILTE (Festival of Education in Learning and Teaching Excellence), among others. These are currently made available through industry and business sources, government agencies and science centres and projects (Appendix III). Many of these initiatives are supported by public funding through Science Foundation Ireland. Science Foundation Ireland also funds major research centres through which it supports the delivery of a broad range of education and outreach activities. It also directly manages national projects such as Science Week. While such activities contribute in a loose way to lifelong learning for STEM teachers, a formal framework for CPD would provide a more targeted approach that would yield a major dividend for STEM teachers.

Science in primary schools is a single component of a three-element strand of the curriculum, Social, Environmental and Scientific Education (SESE), which consists of three subjects: Science, Geography and History. It is unlikely to command a major portion of the timetable and it is taught by generalist teachers. Formal science learning is often supplemented by informal learning through initiatives such as Discover Primary Science and Maths in Primary Schools and other informal events and competitions. An expansion of Science-based CPD and better use of CPD days would lead to improved science teaching in primary schools. Better use and recognition of the role of the informal STEM education provided by various stakeholders, such as enterprise partners, will support CPD.

Proposed changes in post-primary education have resulted in STEM subjects being more focused on deeper understanding of core concepts, as well as the application of knowledge and understanding. This level of engagement demands more time to be successful.

Concern about the state of the physical sciences in post-primary schools has persisted for many years. Physics, and to a lesser extent chemistry, attract low numbers at Leaving Certificate level. The majority of Junior Cycle science teachers are qualified in biology. This leads to a skewed distribution of STEM teacher qualifications, and suggests the need for a CPD strategy targeted at up-skilling non-specialist or out-of-field teachers of physics and chemistry in the short-to-medium term.

Proposed Actions

- Develop a coherent policy framework for CPD in STEM education, recognising that this may be part of a broader CPD framework for teachers. The DES, together with partners such as the NCCA, Teaching Council, HEIs, SFI, subject associations and the private sector, should address this as a matter of urgency.
- Support STEM teachers (primary and post-primary) financially and through appropriate career opportunities to embrace CPD and lifelong learning in their STEM disciplines (and related pedagogy) as a means of advancing their professional development.
- Develop a common currency for assessing and accumulating CPD elements in STEM education for accreditation purposes. Such currency units (such as credits or points) should be used in defining professional recognition from the Teaching Council.
- Develop CPD programmes for primary teachers to expand their knowledge in STEM subjects in order to build capacity in schools for the role of 'STEM Champions'.
- Working with the Teaching Council, all stakeholders should ensure that a comprehensive suite of STEM CPD programmes is available to post-primary teachers as part of their professional learning requirements under the forthcoming Teaching Council Framework for Continuous Professional Learning.
- Develop STEM up-skilling programmes in physics, chemistry and biology for science teachers (post-primary) so that they can upgrade their registration status to a level of being qualified to teach in these subjects. Such programmes could build on the successful DES blended education model developed for the out-of-field teachers of mathematics (at UL).
- Maintain a strong CPD programme in mathematics, because mathematics is fundamental for all STEM education.
- Link formal and informal STEM education providers under a national initiative, such as SFI Discover, to create opportunities for non-traditional CPD for STEM teachers (e.g. museums, zoos, science galleries).

TERM OF REFERENCE 3:

THE INTRODUCTION OF NEW TEACHING AND LEARNING MODALITIES THAT WOULD ENHANCE STEM EDUCATION IN OUR SCHOOLS

Introduction

Inquiry-Based Learning (IBL) and Problem-Based Learning (PBL) approaches encourage students to engage with and understand scientific and mathematical concepts in the context of real applications. It is common to all STEM subjects, although there are specific differences for particular subjects.

Inquiry-Based Learning (IBL) puts the emphasis initially on curiosity and observations, which are then followed by problem-solving and experimentation. Through the use of critical thinking and reflection, students are able to make meaning out of gathered evidence, and make sense of the natural world.

In PBL problems are posed in such a way that students need to seek new knowledge before they can solve them. Rather than seeking a single correct answer, students interpret the problem, gather the information needed to identify possible solutions, and then evaluate options and present conclusions.

In Ireland, recently revised curricula in mathematics and science provide a timely opportunity to introduce new teaching, learning and assessment modalities to enhance STEM education.

Current practice

New curricula in mathematics, introduced under the 'Project Maths' initiative for Junior Certificate and Leaving Certificate, promote problem-solving and IBL, where students use mathematics in every-day contexts. The current Junior Certificate science curriculum is inquiry-based, with 24 mandatory investigations, worth 10% of the total marks awarded in the Junior Certificate (Coursework A). The investigations are intended to be open-ended, but, in reality, many students follow text-book instructions to complete them. Teachers report that because of the large number of investigations, there is not enough time for extended engagement. Coursework B is the second part of the practical assessment. Students choose either to carry out and report on one investigation of their own choice, or two investigations set by the State Examinations Commission (SEC). The majority of students (approximately 90%) choose to carry out the investigations set by the SEC. A new specification for Junior Cycle science will be implemented in schools in September 2016. Assessment will include two Classroom-Based Assessments (CBA) assessed by the teacher. External assessment will consist of an assessment task based on the CBAs and a written examination.

Each Leaving Certificate syllabus has specified mandatory experiments that must be reported on; all of the experiments are prescribed by the syllabus, and the reports do not form part of the assessment. The practical work that students carry out at Leaving Certificate is narrowly defined. It focuses on what is done in laboratories using common laboratory equipment. Activities that are not rewarded by the assessment are unlikely to take place.

There are currently no systemic links between formal and informal STEM education in Ireland. Formalising links between them in some structured way (e.g. by students using outputs from informal education settings as evidence of learning) has the potential to expand the possibilities for student engagement in authentic scientific investigation.

Key issues

Assessment strongly influences the learning process and the way students think about themselves. The nature of the assessment used for STEM subjects will have a strong influence on how successfully IBL and PBL approaches are implemented in schools. Such assessments should be designed to measure students' ability to collaborate, diagnose problems, critique experiments, plan investigations, research information, construct models, debate with peers, form coherent arguments and create and co-create new content. Planned changes to assessment arrangements at Junior Cycle will provide schools with the opportunity to devise and self-assess short courses.

The significant shift in STEM education towards inquiry-based and problem-based learning necessitates a similar shift in the type of continuing professional development offered to teachers. A blended learning approach to CPD offers the advantage of a variety of online courses as well as learning events where there are opportunities for collaborations amongst teachers in which they engage in active learning. Active learning builds knowledge, understanding, and ability. Such an approach allows teachers to tailor their own learning and develop their pedagogical content knowledge (PCK); when teachers develop teaching and learning skills in the context of IBL and problem-solving, they also increase their content knowledge. Professional development activities that model good, inquiry-based science and mathematics teaching and are sustained, contextual, and require participation and reflection are more likely to translate into good classroom practice and support teachers to use new innovative pedagogies, in contexts that are engaging and applicable to students' lives.

Curriculum materials that emerge from research and practice to promote teacher learning are required in addition to text-books and other student-centred resources. Text-books have a particular role in curriculum, but, in the absence of other sources, teachers come to rely on them for methodology as well as content. Textbooks may over-emphasise factual knowledge as opposed to students' understanding about the processes of STEM. 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 review of mathematics text books based on the revised mathematics specifications (O'Keeffe & O'Donoghue, 2011). Scoilnet.ie is the DES official portal for online resources in Education. The website is managed by PDST Technology in Education on behalf of DES and has been developed as a support for teachers at both primary and post-primary levels. Scoilnet.ie has over 2000 resources aligned with STEM subjects.

Informal, extracurricular learning environments, such as science fairs, competitions, coding clubs (e.g. CoderDojo) and open education resources (e.g. Khan Academy) offer a rich opportunity for students to learn and apply STEM concepts. Such initiatives allow students to develop strong ownership of their projects and results, to apply a hands-on experimental and problem-based learning approach, to work on topics that motivate and interest them, to develop their own investigations and models and to communicate their results.

IBL pedagogy can encourage links between formal and informal education, meaning that learners can draw on their learning in informal settings, supported by interventions from enterprise, scientists, researchers, engineers, universities, cities, parents and others.

Proposed Actions

- Put essential measures in place to support the implementation of inquiry-based learning as part of the revised curricula for STEM subjects. Innovative assessment that aligns with inquiry-based teaching and learning should be developed.
- Develop a means of recognising participation in informal (extra-curricular) STEM events and activities (e.g. Science Fairs, BTYSTE, SciFest, CoderDojo, Intel MiniScientist) into the STEM curriculum and assessment at Primary and Post-primary levels, e.g. in an e-portfolio of achievement. Such digital archives of learning and personal development need to become part of the assessment for learning. The model used for the Science Foundation Ireland Discover Primary Science and Maths programme at primary school could be explored.
- Develop extensive curricular materials for teachers that operationalise learning outcomes in STEM subjects at primary and post-primary levels.
- Promote real engagement with fundamental science concepts and principles through application to real-life situations and practical work.
- Foster evidence-based STEM education research in Ireland in order to support the introduction of new modalities in STEM teaching, learning and assessment.

TERM OF REFERENCE 4:

THE USE OF TECHNOLOGY TO ENHANCE STEM LEARNING

Introduction

Recent decades have seen a shift in focus from technological innovations themselves, such as Information and Communications Technology (ICT), to the complex interaction between ICT, teachers and learners. Developments in education happen in concert with global online trends in digital technology. It is estimated that by 2020 there will be more than 21 billion connected internet devices, with wearable technology estimated to grow faster than both smartphones and tablets resulting in an explosion of data and resources that can be used to support STEM teaching, learning and assessment.

The use of digital technology and big data to deliver and personalise education continues to grow. Personalised and adaptive learning pathways, MOOCs, blended learning, online communities of learning and practice together with rich, open educational resources (OERs) and environments provide educators with new and enhanced teaching and assessment assets and methodologies. Technology facilitates greater learner engagement, social collaboration and motivation where learners develop 21st Century skills as they access and exploit the multiple resources available to them.

Current practice

To date there has been uneven adoption of technology to enhance teaching, learning and assessment in Irish schools. However, the new *Digital Strategy for Schools* 2015-2020 (*Enhancing Teaching, Learning & Assessment*) was launched in October 2015. This strategy considers and builds on earlier policies to provide a framework for better integration of ICT in schools and improved practice of ICT usage. It sets out a clear vision for the role of digital technologies in enhancing teaching, learning and assessment in schools '*so that Ireland's young people become engaged thinkers, active learners, knowledge constructors and global citizens who participate fully in society and the economy.*'

The Strategy has been developed around four main themes:

1. Teaching, Learning and Assessment using ICT
2. Teacher Professional Learning
3. Leadership, Research and Policy
4. ICT Infrastructure.

An Implementation Plan, to deliver on the overarching objectives set out in the 5-Year Digital Strategy and framed around the four themes, is currently underway. The Strategy recognises that schools require public investment in their ICT infrastructure and, accordingly, a fund of €210m to support the implementation of this Strategy is available beginning with an investment of €30m in the next school year (2016/2017), rising to €50m a year towards the end of the Strategy.

While many individual schools are currently using some online and hardware resources, a system-wide approach is needed so that all schools have a solid IT infrastructure that is agile, able to adapt to developments in digital technology, and that supports the development of online repositories (developed by external experts and by students and teachers in schools) of appropriate teaching and learning resources. Under the existing Broadband Access Programme for Schools, the DES provides for the supply of internet connectivity for all recognised primary schools. The need to improve Broadband connectivity to primary schools is recognised in the Digital Strategy for Schools and the DES will collaborate with DCENR to provide enhanced broadband to all primary schools. Since 2014, all post-primary schools have been connected with 100Mbit/s. Management of IT infrastructure in schools is often done on an informal basis by teachers with an interest in technology. As use of technology grows in schools, however, that situation is no longer sustainable. Resources will be required for management of the school IT infrastructure and for upskilling teachers in the in the use of technology, providing courses that influence pedagogical orientation (e.g. towards a constructivist, inquiry-based approach), as well as CPD on the pedagogy associated with the use of technology in teaching, learning and assessment.

The Professional Development Service for Teachers (PDST), which operates under the remit of the DES, is the largest single support service offering professional learning opportunities to teacher and school leaders in a range of pedagogical, curricular and education areas. Within PDST, there is a subdivision focused on the role of Technology in Education. The PDST (Technology in Education – TIE) is tasked with promoting the integration of ICT in education in first and second level education in Ireland. This is achieved through providing a range of ICT-related support services to schools and engaging with policy development and strategy on a national level. The PDST is one of the lead partners identified in the Digital Strategy for Schools and works collaboratively with other Support Services to ensure that ICT is embedded in the Planning, Design and Delivery of all teacher education courses and programmes that will be further developed under the Digital Strategy for Schools. The PDST-TIE also provides advice to schools on ICT equipment and digital learning tools that are best suited to support learning and teaching in schools. The PDST-TIE also manages *Scoilnet.ie*, which is the Department's official Portal for Irish Education. Scoilnet is a 'referratory' of more than 12,000 resources that are aligned with the Primary School Curriculum and Post-Primary Subject Syllabus. Since May 2014, it is a growing repository of user-created/referred resources enabling educators to discuss, rate and use items within their own environments. This facility will be further enhanced under the Digital Strategy for Schools.

Key issues

The use of digital technology has significantly impacted on the way teachers teach and assess and on the way learners learn. The rate of change in digital and mobile technology means that many of today's teachers who would not have used digital assets during their formative training are now tasked with teaching a generation who have grown up with digital technology. Pre-service and CPD programmes are necessary to update teachers on how best to develop and deploy technology-enhanced teaching and learning in the classroom. This is a key component of Theme 2 of the Digital Strategy for Schools, which specifically targets Teacher Professional Learning, from initial teacher education through to CPD. The need to enhance the access to, and impact of, CPD for teachers through extending CPD delivery formats to include online and blended learning programmes is a key feature.

Digital technology supports multiple approaches to learning, including differentiated learning where different personalised learning pathways within a learning environment are generated for individual learners. Diagnostic assessment can be used to lay out an individual's learning pathway where learning is data-driven and adapts to change and improves learning over time for each learner. These advances can only be exploited if teachers are confident and have been educated in the benefits of their use. An objective in the Digital Strategy is to provide information to teachers on innovative ways to use digital technology more actively in their teaching which will facilitate more active learning for students.

Technology facilitates the 'flipped classroom' model, whereby learners use online resources to work through core knowledge concepts in their own time. Learners come to lessons prepared to discuss and present the concepts and their applications to their peers and teachers. In such circumstances learners become teachers while teachers become learners. The success of the MATHletes (now called LearnStorm) national competition in recent years is an excellent example of the use of the 'flipped classroom' model for enhanced engagement with mathematical problem-solving through the use of the Khan Academy free online platform of resources.
ICT also supports the development of online communities of learning and practice. Such communities allow for the sharing of information, curriculum and practice where educators and others share and co-develop new rich multimedia content that supports learning outcomes. Scoilnet brings together existing resources and facilitates authenticated 'crowdsourcing' to promote idea and resource sharing amongst the education community. An objective of the Digital Strategy for Schools is to provide access to Open Educational Resources (OERs) and to develop strategic partnerships with relevant cultural, educational and sporting bodies in order to adapt relevant content into useful learning and teaching resources

ICT allows for greater communication and engagement between schools, the local community, enterprise and parents. Many enterprises already support local education initiatives either through community and social responsibility programmes or local volunteer programs. The use of digital technology can and should be used to further enhance these engagements. Examples might include the use of online mentors to assist schools/learners with their STEM activities, using existing in-house digital assets to bring real science and engineering into the classroom and new forms of CPD to educate teachers in computer science. Similar engagements can be facilitated at an international level between schools as well as between schools and research facilities many of whom have outreach programmes and mandates.

New hardware devices (e.g. Tablets, 'Maker boards and Kits' for electronic makers including sensors, motors etc., 3D printers etc.) present new opportunities for teaching and learning. By using additional components, teachers and learners can deploy sensor technology to collect data (i.e. connect the school to weather stations and the wider internet of things) and use the assembled data for a richer educational experience. By using maker boards and kits, learners can design and make systems that address meaningful, authentic problems, which enhance lives and support people and communities.

Data analytics provides real-time information about learners' behaviour and academic progress, which enable teachers to make better-informed decisions that empower them to react to the learners' progress.

Technology facilitates formative and summative assessment methodologies that can be used to help learners develop the logical, critical, and creative thinking abilities necessary for the further pursuit of training, education and for everyday living.

The quality of the type of work a teacher assigns strongly predicts the quality of the work that a learner completes. Based on a recent study to assess 21st century skills acquisition, over 90% of the variances in student scores was not due to differences in the students but differences in the classroom learning activities the students completed (SRI International, 2010).

Technology-facilitated education has the potential to transform traditional science and mathematics classrooms from a teacher-directed model to a facilitatory or constructivist model where the teacher is supporting and co-constructing personalised teaching and learning experiences for the learners, both individually and collaboratively.

With the explosion of digital media content and resources, it can be difficult for learners and teachers to navigate, source and evaluate appropriate and content-relevant material. Managed, cloud-based repositories afford opportunities to build and curate relevant and appropriate materials where communities of learners and teachers can collaborate. Because teachers have limited time available to them, it is crucial for the system data can be accessed in a manner that is easily understandable and digestible, but still allows them to tailor a student's learning experience. To support this change, a system of IT Learning Support will need to be developed in schools. Instead of predominantly supporting the school's technical infrastructure and device management, IT decision makers will need to take on a role where they become enablers of learning who help teachers and learners to exploit the full potential of the technology to support teaching and learning.

Proposed Actions

- Develop a suite of 'Technology-Enhanced Learning' (TEL) CPD programmes in STEM disciplines for teachers at primary and post-primary levels.
- Exploit advances in digital technology to support multiple approaches to learning, including personalised and adaptive learning pathways that will enable students to learn in a manner optimised for their own personal needs.
- Support the establishment of online communities of Learning and Practice and provide support for the creation of rich multimedia educational content.
- Support the introduction of digital technology to facilitate international collaboration in STEM subjects between schools, and between schools and research facilities (e.g. remote telescopes, remote laboratories).

- Provide a central (cloud-based) repository for digital learning and teaching resources in STEM subjects, approved by the Department of Education and Skills and teaching bodies. This should also include a collaborative space for teachers and learners with a focus on active and inquiry-based learning.
- Exploit digital technology in promoting and facilitating new engagements between schools and enterprises, e.g. the use of online mentors to assist schools/learners with their STEM activities; using digital technology to bring real science and engineering into the classroom; new forms of CPD to educate teachers in computer science.
- Promote and facilitate hardware-enabled approaches to technology learning, e.g. Tablets, Maker boards and kits; 3D Printers etc.
- Support the development of a system of IT Learning Support in schools. This would act as a resource to staff and students in the ongoing introduction of new digital technology.

TERM OF REFERENCE 5:

THE PROMOTION OF STEM CAREERS AND THE IDENTIFICATION OF METHODS TO ENHANCE THE ENGAGEMENT OF STUDENTS IN STEM SUBJECTS

Introduction

In recent years in Ireland, there has been a rapidly growing rise in the interest of Government, industry and other stakeholders in the uptake of STEM subjects in schools and third level. This has been driven by the need to ensure that young people gain the skills and aspirations to participate in an increasingly scientific and technological society, and, as citizens, to contribute to a society that is informed about the pivotal role of science and technology in the well-being of society in general.

The Project Maths initiative, and other proposed curricular reforms across the educational continuum, provides a timely opportunity to adopt innovative teaching learning and assessment methodologies, and to work with STEM-related industry and enterprise to make real life visible in science learning.

Placing STEM learning in the context of everyday topics that engage young people will improve students' perceptions about science. Many organisations provide extensive, high-quality curriculum support materials that support STEM learning in context, and accentuate the use of technology to enhance learning (e.g. ESRO[4], RSC[5], IoP[6] SAPS[7], and the UK National STEM Centre.)[8]

Current practice

STEM subjects are widely perceived by students, their parents and career guidance counsellors as being difficult, and not relevant to many young people's lives. Access to better information about the value of STEM qualifications and an understanding of the value of science and mathematics to their future careers will provide young people with incentives to continue studying STEM subjects through to Leaving Certificate and beyond.

Students in DEIS[9] schools (both primary and post-primary) perform less well in national and international tests of achievement in STEM than their peers in non-DEIS schools. Furthermore, as highlighted in Chapter 1, women are vastly under-represented in science and technology careers in Ireland. Regardless of the cause, it is important to encourage and support STEM in all underrepresented groups.

[4] European Space Research Organisation

[5] Royal Society of Chemistry

[6] Institute of Physics

[7] Science and Plants for School

[8] Located at York University

[9] DEIS Delivering Equality of Opportunity in Schools (DEIS) - the Action Plan for Educational Inclusion' was launched in May 2005 and remains the Department of Education and Skills policy instrument to address educational disadvantage

Key issues

Because students' subject choices are often made to secure maximum points in the Leaving Certificate, the perceived difficulty of STEM subjects creates a disincentive for students to carry these subjects through to Leaving Certificate, or to study mathematics at Higher Level. It is notable that there has been a significant increase in the uptake of Higher Level mathematics since the introduction of bonus points in 2012.

Parents and families exert a considerable influence on students' aspirations. This influence operates in many ways, but a key factor affecting the likelihood of a student aspiring to a science-related career by the age of 14 is the amount of 'Science Capital' a family has. The term 'Science Capital' refers to science-related qualifications, understanding, and knowledge about science and how it works, interest and social contacts e.g. knowing someone who works in a science-related job (ASPIRES 2013).

The good work of campaigns to highlight STEM career awareness for students and their parents, such as those funded by Science Foundation Ireland and others, is recognised. There is a need, however, to grow the impact of these initiatives. This can be achieved by increasing the input and support of local STEM enterprises in a collaborative way, thereby ensuring that students and their families are more fully aware of the opportunities that studying STEM can offer for a diversity of careers. Programmes aimed at helping students and their families to understand the transferable value of STEM qualifications would be helpful in inspiring more young people to see science as possible and relevant for their own futures. Local STEM enterprises have a role to play in a concerted, organised initiative, such as the national Smart Futures initiative and similar, to work with schools to demystify the application of STEM disciplines in the work-place and to provide insight into what working as a scientist looks like. Such collaborations also have the potential to provide role-models for students, and increase the idea of community-based education.

Many Irish Higher Education Institutions (HEIs) offer entrance scholarships to students in recognition of their excellence in extra-curricular areas such as sport and performing arts. The recent decision by the seven Irish universities to extend this approach to STEM education by awarding scholarships to winners of the senior sections of the BTYSTE competition is to be applauded. Similarly, the STEM scholarships awarded annually by the Naughton Foundation provide a very important stimulus to STEM careers by recognising high-performing students in schools across Ireland.

In developed countries across the world, large-scale interactive science centres play a key role in attracting young people into careers in science, engineering and technology. Although a range of initiatives and venues across Ireland promote interest in STEM and STEM careers (e.g. Science Gallery, Dublin), there is a significant void in the Irish STEM education environment due to the absence of a first class, hands-on National Science Centre.

Proposed Actions

- STEM disciplines should be promoted as being crucial to personal development and citizenship in the 21st century.
- The career possibilities for students who follow a STEM career path should be highlighted not only to students but also to parents. Parents have a strong influence on students' subject choices. Market STEM qualifications with an emphasis on future economic needs and as a pathway to important, challenging and well-paid careers.
- STEM curriculum and assessment should be linked to wider ethical, legal, and societal issues, such as STEM's role in addressing global challenges (food, water, and energy security; biodiversity loss; etc.).
- Ambitious targets and a sustained, multi-faceted action plan for addressing the gender imbalance in specific STEM disciplines should be established and implemented as a matter of urgency. Particular emphasis should be placed on the marketing strategies and language used in this regard.
- Engineering and technology should be integrated into the structure of science education at all levels, according the core ideas of engineering design and technology with the same status as core ideas in the other major science disciplines.
- Identify and promote the range and diversity of career opportunities available to STEM graduates as early as possible in primary and post-primary schools.
- Avail of partnerships with STEM enterprises (e.g. within the national Smart Futures initiative) to promote STEM careers at all levels in education.
- Promote and facilitate the 'adoption' of a school, or a cluster of schools, by a local STEM industry/enterprise. The support of IBEC and the American Chamber of Commerce in Ireland ('AmCham') may be important in this regard.
- The planned Exploration Station at Earlsfort Terrace, Dublin should be supported by Government as an effective means of stimulating interest in, and engagement with, STEM topics.

CHAPTER 7

CHAPTER 7

Introduction

Our aim as a nation should be to ensure that STEM education in Ireland is of the highest international quality. Our review has identified both positive elements and serious deficits in the current STEM landscape in Ireland. The positive features are to be found in both formal (e.g. curricular reform) and informal education developments, but many are taking place in an uncoordinated, independent fashion, rather than as part of an overarching, coherent, cooperative strategy. On the deficit side, the highest-level concerns are the absence of a clearly-articulated STEM education strategy and the levels of performance achieved in international assessments.

The overall levels of performance and engagement in STEM subjects are not good enough if we aim to provide the best for our nation's children, and if we wish to sustain our economic ambitions for the future. A step-change in STEM performance and outcomes is required throughout the educational system if we are to move our STEM education performance up to the highest levels.

The focus of this report has been to identify pathways to achieving that step-change so that, through implementation of our recommendations, the quality of STEM Education in Ireland will be enhanced considerably and sustainably.

It is clear, and unsurprising, that the role of teachers is central to the changes required. In that regard, it is crucial that a comprehensive, properly-resourced structure is established in order to support teachers in enhancing their role and in embracing the changes that are needed.

Consideration should be given to recognising, by way of an honours system, those teachers who proactively engage and in some instances are leading the changes that are needed.

In making our recommendations regarding STEM education, it is not intended to diminish the significance of any other disciplines. The degree of prioritisation accorded to STEM education is a matter for Government, ideally taking account of available evidence and international best practice.

A Vision for STEM Education in Ireland

Our vision is to provide students in Ireland with a STEM education experience of the highest international quality; this provision should underpin high levels of student engagement, enjoyment, and excellent performance in STEM disciplines.

Achieving the vision for STEM education articulated here will require commitment, investment and early action, together with partnership across all the primary stakeholders in both the formal and the informal learning sectors. It is clear that the most effective approach will involve a coalition of committed partners across government departments (especially DES) and agencies, the enterprise sector, professional and learned societies, teachers and communities. In particular, the enterprise sector has an important role to play in supporting Government in ensuring the provision of a high-quality graduate output aligned with national economic needs. In conclusion, the Review Group believes that this **Vision for STEM Education in Ireland** is achievable through active and early implementation of the Specific Proposed Actions detailed earlier in the report (associated with each Term of Reference) and the following, overarching General Recommendations:

General recommendations

- Produce an integrated National STEM Education Policy Statement with input from, and relevance to, all stakeholders across the continuum of education in Ireland (primary, secondary and third level). This Policy Statement should include a detailed implementation plan with responsibilities and timelines clearly outlined.
- Introduce computer science (including coding) as a Leaving Certificate curriculum subject. This is critical to address the ICT skills deficit in Ireland.
- Establish the STEM 2020 Partnership - a fixed-duration, public-private (enterprise-exchequer) partnership to create a fund to support a prioritised set of agreed, specific initiatives consistent with the recommendations of this report. This would entail pooling of resources from enterprise partners, philanthropy and crowdsourcing with resource-matching by the exchequer (DES, DJEI, SFI) over a five-year period. A fund of €8M per annum for five years, equally subscribed from public and private interests, is envisaged.
- Establish STEM education research as a national research priority with multi-annual, sustained funding commitment through SFI. (The following recommendation would be an excellent means of achieving this).
- Establish a National STEM Education Research Centre, comprising a small number of regionally distributed nodes (based on the highly successful UK Science Centre model). This national centre would act not only as a centre of excellence for research and innovation in STEM education, it would also provide locations for delivery of CPD programmes for teachers.
- Create an annual ‘Excellence in STEM Teaching’ award scheme to recognise those teachers who are pioneering innovations in STEM education and who are outstanding educators.
- While this report has focused almost exclusively on the STEM disciplines and STEM Education in general, it is now well established that the intersection of these areas with the Arts (visual and performing) and Design offers great potential in terms of both cultural advancement and economic development opportunities. With this is in mind, it is important that any future strategy for STEM in Ireland takes account of the STE(A)M hybrid, where A represents the Arts and Design (including design thinking). It is proposed, therefore, that the Royal Irish Academy play a formal role in advancing the thinking on this topic in the Irish context with a view to influencing future policy decisions regarding STEM Education.

CHAPTER 7

All Proposed Actions & General Recommendations

Term of Reference 1:
Preparation of teachers (at primary and post-primary level) for STEM education in Ireland

Proposed Actions:

- The ongoing supply of 'qualified STEM teachers' (at post-primary level) should be a particular focus of the Teaching Council in its planned report on teacher supply to the Minister for Education and Skills.
- The development of specialist STEM teachers ('STEM Champions') should be encouraged in primary schools. Such specialists would work with colleagues to disseminate insights and best practice in STEM Education. A 'STEM Champion' should hold a recognised postgraduate qualification (e.g. in Mathematics Education, Science Education, Technology Education, STEM Education). Support should be provided to primary teachers to gain such qualifications.
- All STEM teaching in post-primary schools should be delivered by qualified STEM teachers (as defined by the Teaching Council), and the imbalance in the proportions of teachers qualified in biology, physics and chemistry should be addressed as a matter of urgency (see TOR 2).
- The minimum entry requirements into the B.Ed. degree programme (for primary teachers) should be reviewed as soon as possible with a view to creating greater equity across core subject areas.
- Students of ITE (primary) programmes should undergo an audit of subject-matter knowledge (SMK) in STEM subjects (mathematics and science) over the course of their programme. Self- or peer-evaluation may be helpful in this regard. Supports should be provided to ensure that students address deficits in their knowledge, e.g. mathematics-learning support.
- Offer incentives (e.g. targeted bonus points per STEM subject up to a maximum of two subjects, for example) to Senior Cycle students seeking to enter concurrent STEM Teacher Education degree programmes (for post-primary) generally but especially in mathematics, physics, chemistry and engineering.
- Support all primary teachers (in ITE) in building their subject matter knowledge (SMK) and pedagogical content knowledge (PCK) in science, mathematics and technology as part of a broader professional portfolio of expertise and related activities.
- Require all primary teachers in ITE to pass all STEM-methodology-related subjects (without compensation) in final examinations, where this is not currently the case.
- Include a formal consideration of STEM education during mentoring of student teachers during their primary school placement.
- Support the active engagement of schools with STEM-related industries across a broad range of fronts (e.g. the possibility of optional placements in STEM industries during primary and post-primary teacher preparation phases should be explored).

Term of Reference 2:

The best methods of supporting the current cohort of STEM Teachers within the system (with a particular focus on Continuing Professional Development)

Proposed Actions:

- Develop a coherent policy framework for CPD in STEM education, recognising that this may be part of a broader CPD framework for teachers. The DES, together with partners such as the NCCA, Teaching Council, HEIs, SFI, subject associations and the private sector, should address this as a matter of urgency.
- Support STEM teachers (primary and post-primary) financially and through appropriate career opportunities to embrace CPD and lifelong learning in their STEM disciplines (and related pedagogy) as a means of advancing their professional development.
- Develop a common currency for assessing and accumulating CPD elements in STEM education for accreditation purposes. Such currency units (such as credits or points) should be used in defining professional recognition from the Teaching Council.
- Develop CPD programmes for primary teachers to expand their knowledge in STEM subjects in order to build capacity in schools for the role of 'STEM Champions'.
- Working with the Teaching Council, all stakeholders should ensure that a comprehensive suite of STEM CPD programmes is available to post-primary teachers as part of their professional learning requirements under the forthcoming Teaching Council Framework for Continuous Professional Learning.
- Develop STEM up-skilling programmes in physics, chemistry and biology for science teachers (post-primary) so that they can upgrade their registration status to a level of being qualified to teach in these subjects. Such programmes could build on the successful DES blended education model developed for the out-of-field teachers of mathematics (at UL).
- Maintain a strong CPD programme in mathematics, because mathematics is fundamental for all STEM education.
- Link formal and informal STEM education providers under a national initiative, such as SFI Discover, to create opportunities for non-traditional CPD for STEM teachers (e.g. museums, zoos, science galleries).

Term of Reference 3:

The introduction of new teaching and learning modalities that would enhance STEM education in our schools

Proposed Actions:

- Put essential measures in place to support the implementation of inquiry-based learning as part of the revised curricula for STEM subjects. Innovative assessment that aligns with inquiry-based teaching and learning should be developed.
- Develop a means of recognising participation in informal (extra-curricular) STEM events and activities (e.g. Science Fairs, BTYSTE, SciFest, CoderDojo, Intel MiniScientist) into the STEM curriculum and assessment at Primary and Post-primary levels, e.g. in an e-portfolio of achievement. Such digital archives of learning and personal development need to become part of the assessment for learning. The model used for the Science Foundation Ireland Discover Primary Science and Maths programme at primary school could be explored.
- Develop extensive curricular materials for teachers that operationalise learning outcomes in STEM subjects at primary and post-primary levels.
- Promote real engagement with fundamental science concepts and principles through application to real-life situations and practical work.
- Foster evidence-based STEM education research in Ireland in order to support the introduction of new modalities in STEM teaching, learning and assessment.

COMBINED REPORT OUTCOMES:

Term of Reference 4:

The use of technology to enhance STEM learning

Proposed Actions:

- Develop a suite of 'Technology-Enhanced Learning' (TEL) CPD programmes in STEM disciplines for teachers at primary and post-primary levels.
- Exploit advances in digital technology to support multiple approaches to learning, including personalised and adaptive learning pathways that will enable students to learn in a manner optimised for their own personal needs.
- Support the establishment of online communities of Learning and Practice and provide support for the creation of rich multimedia educational content.
- Support the introduction of digital technology to facilitate international collaboration in STEM subjects between schools, and between schools and research facilities (e.g. remote telescopes, remote laboratories).
- Provide a central (cloud-based) repository for digital learning and teaching resources in STEM subjects, approved by the Department of Education and Skills and teaching bodies. This should also include a collaborative space for teachers and learners with a focus on active and inquiry-based learning.
- Exploit digital technology in promoting and facilitating new engagements between schools and enterprises, e.g. the use of online mentors to assist schools/learners with their STEM activities; using digital technology to bring real science and engineering into the classroom; new forms of CPD to educate teachers in computer science.
- Promote and facilitate hardware-enabled approaches to technology learning, e.g. Tablets, Maker boards and kits; 3D Printers etc.
- Support the development of a system of IT Learning Support in schools. This would act as a resource to staff and students in the ongoing introduction of new digital technology.

Term of Reference 5:

The promotion of STEM careers and the identification of methods to enhance the engagement of students in STEM subjects

Proposed Actions:

- STEM disciplines should be promoted as being crucial to personal development and citizenship in the 21st century.
- The career possibilities for students who follow a STEM career path should be highlighted not only to students but also to parents. Parents have a strong influence on students' subject choices. Market STEM qualifications with an emphasis on future economic needs and as a pathway to important, challenging and well-paid careers.
- STEM curriculum and assessment should be linked to wider ethical, legal, and societal issues, such as STEM's role in addressing global challenges (food, water, and energy security; biodiversity loss; etc.).
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- Avail of partnerships with STEM enterprises (e.g. within the national Smart Futures initiative) to promote STEM careers at all levels in education.
- Promote and facilitate the 'adoption' of a school, or a cluster of schools, by a local STEM industry/enterprise. The support of IBEC and the American Chamber of Commerce in Ireland ('AmCham') may be important in this regard.
- The planned Exploration Station at Earlsfort Terrace, Dublin should be supported by Government as an effective means of stimulating interest in, and engagement with, STEM topics.

COMBINED REPORT OUTCOMES:

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- Create an annual ‘Excellence in STEM Teaching’ award scheme to recognise those teachers who are pioneering innovations in STEM education and who are outstanding educators.
- While this report has focused almost exclusively on the STEM disciplines and STEM Education in general, it is now well established that the intersection of these areas with the Arts (visual and performing) and Design offers great potential in terms of both cultural advancement and economic development opportunities. With this is in mind, it is important that any future strategy for STEM in Ireland takes account of the STE(A)M hybrid, where A represents the Arts and Design (including design thinking). It is proposed, therefore, that the Royal Irish Academy play a formal role in advancing the thinking on this topic in the Irish context with a view to influencing future policy decisions regarding STEM Education.

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Our vision is to provide students in Ireland with a STEM education experience of the highest international quality; this provision should underpin high levels of student engagement, enjoyment, and excellent performance in STEM disciplines.

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APPENDICES

APPENDICES

Appendix I: Composition of STEM Education Review Group (STEMERG):

- Chair: Prof. Brian MacCraith MRIA, President, Dublin City University
- Dr. Thérèse Dooley, Senior Lecturer In Mathematics Education, St. Patrick's College, Dublin City University
- Mr. Bill Kearney, Director Dublin Lab, IBM Software Group
- Mr. Seán MacCormaic, Chair of the Irish Maths Teachers Association
- Prof (Emeritus) John O'Donoghue, Director (2008-2014), NCE-MSTL, University of Limerick
- Dr. Pádraig Ó Murchú, formerly Education & Research Manager, Intel
- Dr. Anna Walshe, National Council for Curriculum and Assessment

Assisted by:

- Dr. Claire O'Connell, Science Communicator and Journalist
- Ms. Ciara Molloy, Department of Education and Skills

Appendix II: Routes to registration for primary and post-primary teachers in Ireland

Initial Teacher Education (Primary and post-primary sectors)
Established in March 2006, the Teaching Council regulates the teaching profession in Ireland. The Council (2011b, p. 5) espouses a policy position on Teacher education based on a continuum model that:

> *encompasses initial teacher education, induction, early and continuing professional development and, indeed, late career support, with each stage merging seamlessly into the next and interconnecting in a dynamic way with each of the others*

The Sahlberg Report (DES, 2012) was the proximate cause for the recent reform of initial teacher education provision initiated by Ruairí Quinn T.D., Minister for Education and Skills, which is ongoing and is being carried through by the Teaching Council. The requirements for teacher registration (primary and post-primary) are set out in the Teaching [Registration] Regulations 2009 as provided for in Section 30 of the Teaching Council Act 2001 (Teaching Council, 2009). Under the regulations, there are two main routes to registration: the concurrent model and the consecutive model.

Routes to registration for primary teachers

- **Concurrent model** - completion of a concurrent degree qualification in primary initial teacher education (usually B.Ed.), carrying at least 180 ECTS (European Credit Transfer and Accumulation System), combining Studies in the Foundations of Education, Professional Studies and a Practical Teaching Programme.
- **Consecutive model** - completion of an undergraduate degree and the completion of a post-graduate programme of initial teacher education, carrying at least 90 ECTS, to include the areas of Studies in the Foundations of Education, Professional Studies and a Practical Teaching Programme.

In both entry routes, pre-service teachers are expected to engage in courses of relevant studies in the pedagogy of the entire range of subjects included in the Primary School Curriculum, including STEM subjects. Furthermore, the courses are directed towards pupils in classes from Junior Infants to Sixth Class. HE Institutions engaged in primary teacher education

- Church of Ireland College of Education (undergraduate only).
- Coláiste Mhuire/Marino Institute of Education.
- Froebel College of Education (Maynooth University).
- Mary Immaculate College.
- St Patrick's College, Drumcondra.
- Hibernia College (postgraduate only).

The minimum academic requirements for students entering primary ITE through the CAO process are:

- Grade C3 on a Higher Level paper in not less than three subjects.
- Grade D3 in three other subjects.

Essential Subjects are:

- Irish: Grade C3 Higher Level.
- English: Grade C3 Ordinary Level or D3 Higher Level.
- Mathematics: Grade D3, either Ordinary or Higher Level.

Mature students and students of the post-graduate diploma in education who have completed their Leaving certificate after 1969 must also meet these requirements. In June 2011, the TC initiated a consultation process in relation to revised minimum entry requirements for entry onto ITE programmes. In particular, there is a focus on issues around entry requirements in mathematics and English.

Initial Teacher Education (Post-primary sector)

Routes to registration for post-primary teachers (STEM included)

Under the regulations there are two main routes to registration:

- **Concurrent model** - completion of a concurrent degree qualification in post-primary initial teacher education combining study of one or more approved curricular subjects with teacher education studies encompassing professional studies, foundation studies and school placement all geared towards the post-primary age range (typically 12-18 years).
- **Consecutive model** - completion of an undergraduate degree, which enables the holder to teach at least one approved curricular subject and the completion of a postgraduate programme of initial teacher education geared towards the post-primary age range (typically 12-18 years).

At present the Teaching Council distinguishes between applicants who seek registration (a) on or before 31 December 2016 and (b) on or after 1 January 2017.

HE Institutions engaged in post-primary teacher education (STEM subjects)

All 7 of the Irish universities, and some other HE institutions, are engaged in STEM teacher education (consecutive and/or concurrent model):

- Dublin City University (consecutive and concurrent)
- University College Cork (consecutive and concurrent)
- NUI Galway (consecutive and concurrent)
- Maynooth University (consecutive and concurrent)
- Trinity College Dublin (consecutive)
- University College Dublin (consecutive and concurrent)
- University of Limerick (consecutive and concurrent)
- Dublin Institute of Technology (consecutive)
- Hibernia College (consecutive)

Over the years, Irish universities have developed specific undergraduate degree programmes (Level 8) in STEM subjects that enable prospective post-primary teachers to qualify as post-primary teachers in science and mathematics following the consecutive model.

There has been sustained interest and development in the concurrent model in our universities over a number of years; concurrent ITE programmes in STEM subjects are available in a number of universities including Dublin City University (Science/Mathematics), NUIG (Mathematics), UL (Biology, Chemistry, Physics, Mathematics, Technology).

Registration requirements for STEM teachers

Primary teachers and STEM

Primary teachers are generalist teachers and are registered as such by the Teaching Council. There are no specialist STEM teachers in Irish primary schools. While all primary teachers receive some preparation in mathematics, science and digital learning through 'Professional modules', elective options in STEM subjects are offered. However, relatively small numbers of teachers-in-ITE can avail of these because of their elective nature. From September 2014, there is a particular compulsory aspect of ITE devoted to Literacy and Numeracy.

Current approach to registration of post-primary STEM teachers

As of March 2011, the Council revised its criteria for all approved curricular subjects, including STEM subjects, to be implemented for all new entrants to the profession from 1st January 2017. Graduates from con-current programmes will be registered, provided their programme has been validated by the Council (Teaching Council, 2013). Registration is determined by meeting the Council's criteria for at least one curricular subject, and the Council also retains an indicative list of degrees that in the past have been deemed to meet the requirements for named subjects. Given that the content of degrees and of modules within degrees can change over time, it is very important that applicants read this list in conjunction with the Subject Specialist Criteria.

http://www.teachingcouncil.ie/_fileupload/Registration/General-and-Special-Requirements-for-Degree-Recognition-June2011%2053901607.pdf

List of Recognised Degrees

The Teachers' Registration Council, the precursor to the Teaching Council, operated a 'Qualifications List'. This was made up of various degree programmes in Higher Education institutes that were recognised for entry to a postgraduate programme of initial teacher education in various subjects, including STEM subjects.

Graduates from degree programmes listed on the current Qualifications List must submit their credentials for consideration, and these are vetted against post-primary subject criteria set out by the Council for each subject.

http://www.teachingcouncil.ie/_fileupload/Registration/Subject%20Criteria%20documents/Curricular%20Subject%20Requirements%20up%20to%20Dec%202016.pdf

Consecutive model

This is a 3 + 1 model involving at least a three-year programme (Level 8) in an approved STEM subject followed by a postgraduate programme of initial teacher education (1-year) formerly known as the Professional Diploma in Education and the Higher Diploma in Education (PDE/HDip).

This model will involve a two-year teacher education programme from September 2014, the Professional Master of Education (PME). Other changes for new entrants include meeting requirements based on number of ECTS credits for a degree (minimum 180), and in a subject area and level of study in a degree programme for some essential topics. This is the standard model for the future.

Starting in September 2014, all consecutive (postgraduate) programmes of initial teacher education must be of two years' duration (120 ECTS credits).

Concurrent model

The four-year concurrent undergraduate degree recognised for registration purposes is also specified in ECTS credits (240 for degree), subject area credits and education credits. The quantum of subject area credits and education credits will be consistent across models based on an overall limit of 60 ECTS credits per year of undergraduate degree programme. The Council has published its requirements for new entries in 2017 (dated October 2013).

STEM subjects

The registration requirements for STEM subjects (single subject specialists) follows a standard credit-based model that specifies essential topics and programme level. For example, the model approved for future use in Science is based on subject specific study of 60 ECTS, 40 credits of which must be from a given topic list. Single subject science specialists will be expected to study 10 additional credits of science in each of the other two science subjects of the set Biology, Chemistry and Physics. Mathematics is allotted a total of 60 credits.

Appendix III: Audit of STEM Activity

Introduction

An audit of STEM activity was undertaken by the STEM Education Review Group to inform our deliberations. The objective was to generate an evidence-based assessment of the nature and extent of STEM activity and provision such as CPD, outreach and public engagement particularly as these activities impact STEM education in schools. There was no intention to capture data on formal education programmes in the STEM subjects in the HEIs, *e.g.* Level 6, 7 or 8 programmes, or Master's or Doctoral programmes.

The approach

A list of providers was developed by the Group for this purpose. The list provided a convenient sample of stakeholders and providers of STEM activities and events. The list was not exhaustive and, indeed, it evolved as the audit proceeded. Data from late respondents was added right up to final draft stage. The list included HEIs, the DES, government agencies, learned societies, subject associations, industry, teacher education centres, and a variety of other stakeholders.

The stakeholders and providers surveyed were contacted by email and asked to summarise their STEM activities in the current academic year 2013-14. As part of the process there was a follow-up email or phone contact to remind those included in the survey to make a return. In a small number of cases, data was elicited from websites that were consulted as an alternative data-gathering approach.

A complication that arises in dealing with STEM as a descriptor in collecting survey data is the absence of a global definition of the set of STEM subjects. For example, CAO data describes **Technology** as comprising Engineering, Construction, Computing and Science. No attempt was made in the survey to influence respondents 'common understanding' of STEM as comprising *Science, Technology, Engineering and Mathematics*.

In fact, many respondents simply summarised their STEM activities without keeping strictly to the guide period. The raw data were organised internally for presentation purposes and minor edits were implemented to maintain consistency across respondents and the timeframe.

Observations

The outcome is a surprisingly rich tapestry of STEM activities in Ireland showing a wide geographic spread; clustering around major urban centres with HEIs; a huge variety of activities formal and informal; and the involvement of many stakeholders both public and private. It is convenient to use a small number of recognisable categories to discuss the data including CPD, Outreach, Conferences, and Public engagement, and these are added to the tabular format, however, it must be recognised that the list of categories is not exhaustive nor are the categories mutually exclusive. The study by Davison et al (2008) is an exemplar study in this area covering outreach activities North and South.

The STEM Review Group would like to thank all those who participated for the effort expended on behalf of the Group and the data supplied.

The full audit of STEM activity compiled during the review process can be found at this link: https://www4.dcu.ie/content/upload/stemberg/appendix-III.pdf

Appendix IV: 21st Century Skills

In an attempt to put a working definition on what constitutes 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) (Binkley et al., 2012).

The table below maps the skills, identified in Ireland by the NCCA 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 of 21st Century Skills**	**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	**Tools for working**			Managing information and thinking	Information processing
ICT literacy					
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 and belonging	Managing myself	Being personally effective

Appendix V: Report on STEMERG public consultation.

Introduction

On April 17th, 2014, the Royal Irish Academy hosted a Dialogue on STEM education in Ireland. Invited speakers delivered presentations that tied into the STEM education Review Committee's terms of reference, and the audience was encouraged to ask questions and raise comments. This report summarises main messages from the talks.

Setting the context for the dialogue, Prof. Brian MacCraith, chair of the STEM Education Review Group and President of Dublin City University, spoke about the need to encourage literacy and understanding in STEM. "We have a responsibility as educators in fostering deep knowledge in the STEM space," he said. "We cannot look to a flourishing economy and society without looking to STEM. For the major challenges facing society [such as ageing, climate change] we need a scientifically literate community."

Prof. MacCraith said Ireland wanted to be "best in class" but that there was still a way to go, and he emphasised the importance of dialogue for the work of the Committee. "Today is a critical process for us in gathering viewpoints," he said. "This is primarily about listening to you."

The day-long event was structured around the Group's five terms of reference, and several major discussion points emerged.

Teacher preparation for STEM

Entry requirements for primary teacher training was a strong focus of discussion, with some calling for an honours grade requirement in mathematics. While students can currently qualify for teacher training with a D3 grade at ordinary level in the Leaving Cert, the vast majority of entrants come in with higher grades. However, even those students starting initial teacher education with higher grades may not have a secure relationship with maths.

The low entry requirement highlights the relative perception of importance maths as a subject requirement for teaching compared to, say English or Irish, which need higher grades for entry.
But there was also concern that raising the bar for maths could exclude people who would make good teachers.

The balance between teacher training and STEM subject specialism was also up for discussion. While the need for teaching skills is unquestionable, there were also calls for more training in STEM subjects in initial teacher education.

Many people with PhD-level training in a STEM subject are not automatically eligible to qualify for initial teacher training. Relaxing the restrictions and making entry more accessible for STEM practitioners could help to address the shortage of STEM teachers, but this needs to be grounded in standards.

Supporting/enhancing current cohort of STEM teachers

Industry can contribute to STEM-education initiatives, and while there is much focus on links with multi-nationals, the potential contributions of SMEs must not be overlooked.

In industry there are skills and the will to contribute to education, but the engagement needs direction, and enterprise and educators need to learn to speak the same language. However there are also concerns about industry being closely involved in curriculum development, because the local demand for specific skillets can evolve quickly, and students are mobile, they can move abroad.

Transition Year offers a good opportunity to increase engagement with industry and, more generally, initiatives exist where educators, community and industry can together grow a more STEM-friendly culture, such as the success of Kinsale Community College in the BT Young Scientist and Technology Exhibition. It's important to harness and mainstream what already exists rather than trying to re-invent the wheel.

Learning approaches and assessment
An inquiry-based approach offers one potential way to increase engagement in STEM but we need to look at the barriers or challenges to using it. They could include a mindset that science is a collection of facts, or lack of confidence in teachers who would be working on problems where the answer is as yet unknown.

Assessment was a recurring theme at the consultation event. The assertion was that you get out of a system what you assess, so we need to assess for the outcomes we want to see, which is engaged, STEM-literate students who are reaching their potential in STEM subjects. Similarly, appropriate evaluation and assessment would need to be incorporated into the curriculum for inquiry-based learning approaches, and Ireland should show leadership in this area.

Technology to enhance learning
We are seeing major paradigm shifts in our engagement with technology: moving from systems of recording to systems that engage, and moving from a generation of digital natives to data natives. The challenge is how to use that in education.

Technology can put the learner in the centre of the experience, and it can build in assessment. 'Informal' initiatives such as Sci-Fest, BTYSTE, CoderDojo and the emerging 'maker' culture show the importance of peer-to-peer learning with technology. We need to find ways of transferring the enthusiasm and learning in such initiatives into mainstream education without losing the 'coolness' of the extra-curricular setting. CoderDojo can offer students new insights into STEM, which are then brought back into the classroom through different perspectives, and perhaps influence the coders' peers to want to engage with STEM too. Technology should not replace a teacher, rather it should enhance the learning experience by allowing students to engage with virtual problems or situations that would not be practical in the lab setting in school. Technology can also 'flip' the classroom so students engage with material before coming to class, opening up opportunities for discussion and problem-solving.

Blended learning, or a mix of online and face-to-face, is what many teachers seem to find most comfortable, but there are issues around the lack of time, resources and confidence to implement it. Teachers need more support in this area.

Increasing engagement
STEM subjects need to be visible and accessible for students, and students who have the capacity to get ahead in these subjects need to be challenged and kept engaged.

Transition Year and the short courses in the junior cycle offer potential to increase the STEM offering, but we also need to look to the early years in pre-school, encourage STEM professionals to visit and tell the children about what they do.

We also need to better manage transitions between pre-school and school (moving out of the sandpit), and between primary and secondary (when motivation for STEM can drop), to create bridges for curiosity and engagement.

Kinsale Community School has had huge success at BT Young Scientist and Technology Exhibition - the school has produced several winners at Irish and international level - and there are important lessons to be learned for others in the importance of engaging with local industry and community, and how success can breed success and build a culture of science.
As a general point, casualisation within the teaching profession is an issue - 27 per cent of all second-level teachers are not permanent - this is part of the problem of the visibility and presence of STEM subjects in schools.

General comments
As well as comments mentioned in the specific sections, other themes also arose during the Dialogue. They included the need for more career guidance and information for students and their parents, the need to recognise more fully the value of vocational education and training in STEM and the danger of initiative overload for the education system.

Attendees were encouraged to submit further comments by email.

ACRONYMS

AmCham	American Chamber of Commerce
BT	British Telecom
BTYSE	British Telecom Young Scientist Exhibition
CAO	Central Applications Office
CPD	Continuous Professional Development
CSO	Central Statistics Office
DCENR	Department of Communications and Natural Resources
DCU	Dublin City University
DEIS	Delivering Equality of Opportunity in Schools
DES	Department of Education and Skills
DJEI	Department of Jobs, Enterprise and Innovation
EGFSN	Expert Group on Future Skills needs
EPI'STEM	EPI'STEM
ESRO	European Space Research Organisation
FDI	Foreign Direct Investment
HE	Higher Education
HEA	Higher Education Authority
HEI	Higher Education Institutes
IBL	Inquiry Based Learning
ICT	ICT
IMTA	Irish maths Teachers Associations
IoP	Institute of Physics
IOT	Institute of Technology
ITE	Initial Teacher Education
JC	Junior Cycle
LC	Leaving Certificate
LC(H)	Leaving Certificate (Higher)
MLS	Mathematics Learner Support
MOOC's	Massive Open Online Courses
NCE'MTSL	National Centre for Excellence in Maths and Science Teaching and Learning
NCE'STEM	National Centre for Excellence in Science, Technology, Engineering and Mathematics
OECD	Organisation for Economic Co-operation and Development
OER	Online Educational Resources
PBL	Problem Based Learning
PCK	Pedagogical Content Knowledge
PDST	Professional Development Service for Teachers
PDST TIE	Professional Development Service for Teachers – Technology in Education
PISA	Programme for International Student Assessment
PK	Pedagogical Knowledge
PSGC	Primary School Geography Curriculum
PSMC	Primary School Mathematics Curriculum
PSSC	Primary School Science Curriculum
RDS	Royal Dublin Society
RIA	Royal Irish Academy
RSC	Royal Society of Chemistry
SAPS	Science and Plants for Schools
SEC	State Examinations Commission
SESE	Social, Environmental and Scientific Education
SFI	Science Foundation Ireland
SMK	Subject Matter Knowledge
STE(A)M	Science, Technology, Engineering (Arts) and Mathematics
STEM	Science, Technology, Engineering and Mathematics
STEMERG	Science, Technology, Engineering and Mathematics Education Review Group
TEL	Technology Enhanced Learning
TIMSS	Trends in International Mathematics and Science Study
TOR	Term of Reference
UK	United Kingdom
UL	University of Limerick

A Report on STEM Education presented by the STEM Education Review Group to the Minister for Education and Skills