IOP Institute of Physics In Ireland

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National Council for Curriculum and Assessment
35 Fitzwilliam Square,
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16th January 2014

Re: Junior Cycle Science Consultation

To Whom It May Concern:

The Institute of Physics in Ireland welcomes the opportunity to submit a response to the NCCA consultation on the review of Junior Cycle Science.

The Institute of Physics in Ireland is a scientific membership organisation devoted to increasing the understanding and application of physics in Northern Ireland and the Republic of Ireland. It has over 2000 members, and is part of the Institute of Physics.

The Institute of Physics has a world-wide membership of over 50,000 and is a leading communicator of physics-related science to all audiences, from specialists through to government and the general public. Its publishing company, IOP Publishing, is a world leader in scientific publishing and the electronic dissemination of physics.

This submission was prepared in consultation with the IOP in Ireland's governing committee, its Education Group and with input from members of the Institute working in education at all levels. The attached document highlights key issues of concern to the Institute.

If you require any further information or clarification, please do not hesitate to contact the Institute at the above address.

Yours sincerely

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National Council for Curriculum and Assessment Review of Junior Cycle Science

Response from the Institute of Physics in Ireland

16th January 2014

This response draws upon submissions that the Institute has made to recent consultations in Northern Ireland, Wales and England on similar reviews of qualifications. These submissions were made in conjunction with the Association for Science Education, the Institute of Physics, the Royal Society, the Royal Society of Chemistry and the Society of Biology (known together as SCORE http://score-education.org/home). SCORE have recently published guidelines to help awarding organisations to develop specifications and assessments in the sciences that are challenging, useful, appropriate and engaging.[1] This response draws particularly on these guidelines. Our comments on the content of the curriculum for Junior Cycle Science are confined to physics.

The teaching and learning of science is an essential component of the education of all students. As such the Institute considers that the subject should be a core element of the Junior Cycle curriculum as is currently the case for Irish, English and Maths – ie all students should take the subject and it should have the same hours allocated to it – 240 hours annually as opposed to current allocation of 200 hours. This is particularly important for two reasons: the nature of inquiry based learning and the need for separate identities across the three subject areas of physics, chemistry and biology.

1. Inquiry based learning

The Institute particularly welcomes the emphasis on inquiry based learning in the review paper. However, such learning is time intensive and the Institute strongly believes that additional time should be made available within the school timetable for science. As a comparison, in Northern Ireland students taking physics at GCSE level aged 16 would have 120-140 hours to cover the physics specifications.[2] Assuming equal time spent on each of the areas within the Junior Cycle Science, students have just over 66 hours on physics.

Consideration also needs to be given for the considerable time teachers need to set up experiments. In the UK and elsewhere, schools generally have lab technicians to assist with this aspect of the course. Without such support, teachers are very hard pressed to adequately cover the essential nature of experimental science.

A further issue is the level of previous experience of science which students have on entering secondary school. At present, most have spent relatively little time on science at primary school – 4% compared with an OECD average of 9%.[3] As noted in the NCCA briefing document for the Junior Cycle Science review, many students at primary do not appear to have had frequent experience of engaging with the Primary Science Curriculum. Given this low level of science background, it is clear that students need much more time to absorb fully the core ideas of science.

2. Separate identities of physics, chemistry and biology

We strongly believe that each of the sciences should have separate identities, be taught by subject specialists and that they should be balanced up to the age of 16. At present, the subject Junior Cycle Science is generally taught by a single teacher. According to surveys conducted by the ASTI[4], around two thirds of such science teachers are from a biology background. This greatly undermines the teaching and learning of physics and chemistry and we believe this is a major contributing factor to the poor uptake of physical sciences at Leaving Certificate level compared to that of biology (12% for physics, 60% biology)

The Institute accepts that the situation is unlikely to change in the short term but suggests that it would be worthwhile to carry out a pilot project where the subject science would be shared between specialists in the three subjects to see how this might affect uptake of the subjects at leaving certificate level.

Choosing content in the specifications

Scientific understanding is fundamental to human culture. The sciences are powerful: they provide solutions to complex social and environmental challenges and improve human health and wellbeing. The sciences justify their position in the core curriculum by illustrating this power and developing scientific understanding – contributions that are vital for engaging fully in modern life. They also provide and illustrate ways of thinking that are useful in their own right and an important part of the intellectual development of young people. Specifications for Junior Cycle Science should reflect and engender these contributions.

The main principles for developing specifications, their content and its assessment are listed below. Qualifications in the sciences should be:

- **Preparatory**. Provide a sound basis for careers involving the sciences. They should also provide those who do not take science beyond the age of 16 with a good grounding in the methods and ideas of science.
- **Distinct but interdisciplinary**. Ideas within and across the disciplines are interlinked and part of a consistent and coherent interpretation of the world. SCORE would expect science disciplines to normally be taught as separate subjects by specialist teachers, leading either to qualifications in the three disciplines or to a combined science qualification.
- **Unapologetic**. The specifications should exemplify the power of the sciences whilst also showing that there are limits to what we know and that there are areas of human activity that lie outside the bounds of science.
- **Content.** In later sections we have outlined an overview of the core knowledge and understanding of physics. This section does not define content but rather the areas of ideas from which content should be taken.

- **Rich**. The content should be rich – allowing for a deep understanding of its ideas so students are able to apply their knowledge in other contexts.
- **Comprised of content that earns its place**. Any statement of content should earn its place - it should do one or more of the following:
  - address one or more of the big ideas within the discipline
  - provide opportunities to experience what it means to think scientifically
  - provide opportunities for worthwhile practical work: not only should the content and ideas of the sciences be developed through the judicious use of practical work, the practical work should develop techniques and procedural knowledge that is applicable to carrying out tasks and solving problems in and beyond the sciences.
  - employ knowledge from the mathematics curriculum in a coherent way
  - allow for the development of ideas within a range of contexts, including future, current and historical.
- **Part of the whole picture**. Within a specification, the content should be chosen to allow for effective sequencing as part of a whole, building on prior knowledge and developing understanding to enable further study.

Assessment

Assessment should reinforce the character and ethos of a subject. Examinations in the sciences should assess the subject-specific capabilities of candidates, their understanding and their knowledge, and should also assess the nature, processes and methods of science. Assessment items should be subtle and probing to engender high quality teaching and measure high quality learning. Below we have set out our guiding principles for assessment.

- Assessment driven by the learning outcomes. Definitions of what students will be expected to know and do lead to considerations of how these learning outcomes should be taught and assessed.
- Practical work is intrinsic to the teaching and learning of the sciences and this must be reflected in assessment.
- There should be an emphasis on demonstrating understanding
- There should be opportunities for students to demonstrate the depth of their understanding of scientific concepts and application of mathematical knowledge within the sciences.

Thinking and working scientifically

This section outlines ways in which the sciences and scientists work and how scientific ideas and theories have been developed and established. Students should gain an insight into the working methods of the sciences through authentic experiences in the classroom and laboratory.

To understand the strength of the claims within the sciences, it is crucial to appreciate the processes, evidence and reasoning on which those claims are based. Gathering and interpreting evidence are at the heart of the sciences and should be a part of the sciences at school.

The characteristics of good science

The sciences should allow students to gain an authentic view of what it is like to study and work in the sciences (including thinking like a scientist). Students should be familiar with ideas about the “scientific method” - a body of techniques for investigating phenomena, acquiring new knowledge, or correcting and integrating previous knowledge based on empirical evidence and peer review. The sciences are an important part of students’ cultural inheritance, whether or not they go on to work in the sciences.

Specifically, their learning should engender an understanding that the sciences are characterised by the following:

- **Evidence** – acquiring evidence is essential, as is the ability to undertake evidence-based thinking and logical reasoning;
- **Experiments** –scientific experiments and investigations are key to the clarification and consolidation of theories.
- **Measurement** – the sciences are about observing and measuring phenomena to make predictions to test theories;
- **Prediction** – using established models and laws to make predictions or creating new explanations in real world situations,
- **Construction** – using established laws to make things we know will work;
- **Explanation** – to get closer to a full understanding.
- **Repeatability, reproducibility and validity** and falsification – scientific claims are replicable and should be testable; it is important to understand why a particular interpretation of evidence may be inconsistent.

Practical Work

Practical work sits within thinking and working scientifically and is intrinsic to science teaching and learning. At the end of the Junior Cycle, through practical work, students should develop understanding and appreciation for 'how we know', 'how we find out' as well as 'what we know'. Students should experience a wide range of practical work activities to develop and enhance the following sets of skills and knowledge:

Technical and manipulative skills

Students should develop a range of skills associated with using apparatus and materials with due regard for safety and purpose, in the laboratory and the field. For example:

- Assembling and using apparatus safely, with or without instructions; identifying and rectifying faults
- Making and recording observations using a range of appropriate equipment and techniques; use apparatus to make a series of observations, including over time, by manipulating apparatus
- Using a range of instruments, sensors and techniques, take and record readings and make measurements, taking into account appropriate uncertainty and precision
- Using a variety of standard scientific practical techniques (specified under the subject-specific sections)

Carrying out scientific procedures

Students should develop the knowledge of different scientific procedures that will enable them to do the following steps (both independently and as a complete investigation):

- Plan and design investigations and experiments, both for single variables and for more complex situations; selecting appropriate methods, identifying the appropriate variables to be manipulated or held constant; identifying hazards and minimising risk
- Collect, estimate and determine data, using the techniques outlined above
- Present observations and data meaningfully using tables, charts, drawings and diagrams, following current scientific conventions
- Analyse and interpret observations and data, using calculations and scientific models where appropriate
- Present reasoned explanations with due regard for the quality of the evidence

Knowledge and understanding of scientific concepts

Practical work should also be included in the teaching of science to provide experiences on which students can build their understanding of scientific concepts. It is important that teachers select appropriate activities that build on existing understanding, or challenge students thinking.

Assessment of practical work
Knowledge and understanding of scientific concepts can be assessed through written examination, while technical and manipulative skills can best be assessed through direct observation by the assessor. Assessing the way in which scientific procedures are carried out may need a combination of the two.

Physics content and ideas
Physics is a collection of ways of thinking that have led to a number of very successful descriptions and explanations of the way the world works. An education in physics develops these ways of thinking, which are valuable in their own right and transferable to many other contexts. It also develops an awareness of some general themes - big ideas - and an understanding of a core set of content and explanations within the domains of physics.

Big ideas in physics
The list below is a set of big ideas for 15-16 year olds. They are not intended as a description of physics but rather the impressions and ideas that all school children should experience and develop in their physics education – and that should remain ten years after they stop studying the discipline.

Some of the big ideas are thematic and others come from the domains of physics. They have been listed separately in the sections below. Within the domains of physics, we have included some indicative content – these are not big ideas themselves but represent some of the areas of study that might contribute to developing the big ideas.

Themes

- **Reductionism.** *Physics describes natural phenomena in terms of a small number of laws, which allow predictions to be made on whether and how things will happen.*
- **Universality**. *The laws of physics are universal - they work everywhere.*
- **Unification.** *There is a drive to reduce the number of laws to as small a number as possible, each one expressed in as economical a way as possible.*
- **Synoptic nature.** *Physics is an interlinked totality of ideas that must be consistent with each other. Problems can be approached from many different directions*
- **Cause and effect**. *Events can be discussed and understood in terms of causes and effects: what makes things happen the way they do.*
- **Mathematical techniques**. *Physical laws can be expressed in a mathematical form. Physicists develop mathematical models to describe and predict behaviour.*
- **Conservation.** *Some quantities (charge, mass/energy, matter & momentum) are conserved. These conservation laws lead to powerful restrictions on behaviour.*
- **Equilibrium**. *Equilibrium occurs when two or more external influences are in balance - balanced forces, balanced moments, balanced pressures, equal flows in and out.*
- **Differences cause change**. *For example temperature difference, pressure difference, potential difference, differences in concentration and unbalanced forces.*

- **Inertia**. *Things will tend to stay as they are (including moving at a constant speed) unless something causes them to change.*
- **Dissipation.** *Many processes have an element that is resistive and dissipative. Dissipation is a result of the tendency of a system to become more disordered.*
- **Irreversibility.** *Dissipative processes are irreversible. For example, they limit the usefulness and the lifetime of a resource and determine the arrow of time.*
- **Fields.** *Action at a distance can be understood in terms of fields.*
- **Energy.** *There is a useful accounting tool - energy - that, allows us to do calculations to find out, e.g. how long sources will last, or whether some events can happen.*

From the domains of physics

- **Interactions:** *There are interactions (forces) between objects that can change their shape or the way they are moving.*

  Indicative content areas: Levers and moments; forces that act by contact or at a distance (friction, gravity, electrical and magnetic forces); balanced forces and equilibrium; work and energy stores.
- **Kinematics:** *There are well-established laws of motion that predict the way that objects will move and interact with each other.*

  Indicative content areas: Speed and acceleration; balanced forces and Newton's first law; unbalanced forces, inertia, Newton's second law; Newton's third law, momentum; calculations using energy and power.
- **Waves:** *Waves carry energy from a transmitter and can be detected by a receiver.*

  Indicative content areas: Properties of sound – how we make and hear sounds; properties of light (brightness, shadows, straight lines, images, lenses and colour); properties of waves (refraction, reflection, frequency, wavelength and amplitude); models of radiation; ionising radiations.
- **Electricity and magnetism.** *An electric current is the flow of charge in a circuit and allows us to use a remote supply to do work. Electricity and magnetism are intimately linked by basic laws of physics, a situation that has many important technological consequences.*

  Indicative content areas: Electric charge; electric current in a complete electric circuit; voltage and resistance in a simple circuit; resistors in series and parallel; current in parallel arms of a parallel circuit; potential difference across components in a series circuit; using energy and power to do calculations. Electromagnetic effects: electromagnetic induction; transformers and mains electricity.
- **Matter, particles, atoms and beyond**. *The properties of materials can be understood in terms of constituent particles, their motions and interactions.*

  Indicative content areas: The particle model of matter – kinetic theory; density, expansion, floating and convection; solids, liquids and gases; heating and cooling by conduction, radiation and evaporation; the structure of atoms.
- **Cosmology.** *Physics describes our place in the universe. It also provides theories and models for the origin of the universe and similar questions.*

  Indicative content areas: The solar system and the Earth's place in it; the features and origins of elements, stars (including the Sun), galaxies and the Universe.

The endeavour of physics (thinking like a physicist)
We have referred to the ways of thinking that characterise and are developed by physics. The list below includes some of those ways of thinking:

- **critical thinking and scepticism:** puzzling away at something and taking account of all possible objections to find an explanation that they are certain works;
- **deep understanding:** looking for deeper and deeper explanations; not being satisfied with a superficial description; looking for the most fundamental answer that has predictive power across many domains;
- **seeking consistency:** testing that answers are consistent with experience and all other areas of physics;
- **reason and logic:** striving for logical consistency within arguments;
- **quantitative understanding:** realising that quantitative analysis is necessary for proper understanding;
- **models:** developing models (often mathematical) of systems to make predictions of their behaviour in a variety of circumstances;
- **simplification:** simplifying physical situations to their core elements to enable the use of quantitative models to explain or predict phenomena;
- **approximation and other techniques:** making back-of-the-envelope calculations to test the plausibility of ideas; using techniques that consider limiting or extreme cases;
- **isolating:** isolating physical phenomena to test ideas experimentally;
- **using experiments to test ideas:** refining models through the iterative sequence of experiment -> model -> prediction -> test;
- **excising prejudice:** being able to step outside immediate experience and accept explanations that are beyond ‘common sense’

Practical physics

We would expect that every 15-16 year old has had opportunities to develop a range of practical techniques, procedures and methods. They should have experienced and be confident working with the indicative examples below:

- **electric circuits**: wiring simple series and parallel circuits and measuring potential differences and currents within them using ammeters and voltmeters (analogue and digital);
- **materials**: testing the extension of a spring, using thermometers (with appropriate ranges) for measuring the temperature of a cooling object, determining specific heat capacities and investigating the behaviour of gases;
- **forces**: balancing levers and determining a centre of mass; using newton meters (with different ranges);
- **kinematics**: measuring distance, determining speed and acceleration, investigating the effect on acceleration of changing the force on and the mass of the object being accelerated;
- **optical devices**: focusing a lens, determining the power of a lens, building a pin hole camera or telescope, investigating reflection and refraction in solid transparent blocks, colour mixing;
- **waves**: experiments with sound waves and waves in ripple tanks, measuring the speed of sound;
- **radiations**: experiments with heating and cooling by radiation.

Teacher Support

The Institute of Physics in Ireland has worked closely with the Department of Education and the Professional Development Service for Teachers in the provision of CPD for science and physics teachers throughout its teacher network co-ordinators. They directly provide most of the PDST physics sessions in the Dublin area. In addition they advise, provide content and training for PDST sessions outside Dublin.

Some typical cpd sessions on offer are indicated at:
http://www.iop.org/education/teacher/support/network/cpd-sessions/page_44093.html

In addition IOP provides, free of charge, to PDST and teachers throughout Ireland significant teaching resources such as videos, dvds, posters, lesson plans, careers materials, interactive websites - just a few of these are outlined at:
http://www.iop.org/education/teacher/resources/index.html

The Institute would certainly be very pleased to work with the NCCA in the implementation of the new curriculum.

References:

1. Guidelines for the content of Key Stage 4 qualifications 2013
http://score-education.org/media/12525/ks4%20guidelines%20final%20version.pdf

2. GCSE Subject criteria for physics 2009, Ofqual

http://www.rewardinglearning.org.uk/docs/regulation/gcse_science_criteria_dec09/gcse-subject-criteria-for-physics.pdf

3. 2010 OECD Report, Education at a Glance

4. Junior Cycle Science Survey 2010

http://www.asti.ie/fileadmin/user_upload/Documents/Science.pdf