Junior Science: teaching and learning: science education in the 21st century

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There are several rationales for science education for all (Osborne, 2003). The 'utilitarian' considers knowledge of science to be practically useful for everyone. The 'economic' suggests that society requires a supply of well educated scientists to continue to develop and implement technological advances. The 'cultural' holds that science and technology is one of the great cultural achievements of our civilisation and everyone should be familiar with its major themes. The 'democratic' holds that citizens should be equipped to judge the value and limitations of scientific arguments in issues from stem cell research to global warming.

Science education for all is then justified by these rationales. The 'cultural' and 'democratic' suggest that less importance should be given to a detailed knowledge of science material and more to an understanding of science processes and the major themes of science. Indeed, science is one of the three literacy domains used as indicators of educational attainment in the Programme for International Student Assessment (PISA). It is a core subject in many schools and 90% of students take Science in the Junior Certificate.

The image of science has changed in recent times. Science is seen as responsible for such disasters as Chernobyl and global warming. Science is now gender balanced and research is performed across the globe. Studies in the history and philosophy of science suggest science sits in a culture and incorporates certain values. True objectivity is not possible. There is no single "scientific method". This then reinforces the cultural and democratic rationales for science education and suggests that science processes and the major themes of science should be the core elements in science education for all.

Evidence from education and science education research suggests that constructivism (Driver, 1978), cooperative learning (Johnson, 1994), assessment for learning (Black, 2004), investigative science (Bybee, 2006), problem based learning (Finkle, 1995), cognitive acceleration (Adey, 1994) and student centred learning in general are key elements in the learning of science. This implies a change from an authoritarian, didactic and non discursive delivery of science by teachers to developing autonomous learning and the development of critical reasoning as young scientists by students. It opens opportunities for differentiation and students with special educational needs. It reinforces the need for an emphasis on science process skills and the major themes of science rather than specific content detail.

Science has been revolutionised by advances in ICT. The same could be true of science education (DES, 2008). Sensors can simply capture many types of measurement over many timescales. Video analysis of motion or events captured by simple digital cameras in classrooms is possible. Freely available interactive simulations and models provide engaging representations of scientific theories and models which are otherwise difficult to envisage. Science education also benefits from the general access to advanced information, communication and collaboration systems applicable in all subject areas (Osborne, 2003).

Key advantages are the simple experimental setup, rapid gathering of data and effective production of graphical and other visual representations at the core of science practical work. More time is then available for planning, discussion, interpretation and analysis as required by newer methodologies. ICT can equip students for a deeper engagement in science processes and a better grasp of concepts in the major themes in science.

As part of the Bologna Agreement, all third level courses are to be described in terms of learning outcomes to facilitate labour mobility in an open market while in second level reforms across the world, there is a move towards less content and a delineation of key skills learned in appropriate contexts (NCCA, 2005). The broader picture of accelerating change means that to prepare students for the future they should learn how to adapt to changing collaborative environments and the skills required for lifelong learning. Science process skills sit firmly in this framework.

Rationales, education research, ICT advances and changes in education systems argue for an emphasis on science process skills.

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Challenges

Many challenges remain. It may not yet be generally appreciated how coursework can be approached in a variety of ways and that coursework B 'own choice' is an option which rewards student science investigation skills: it best represents the intentions of the syllabus. There remains some focus on content knowledge. Although ICT has been promoted consistently in science education (DES, 2008), ICT pedagogical skills require further development. Specialist and non-specialist teachers require additional support and the processes of science require some clarification for teachers (Williams, 2008). The hard work done at primary level needs greater recognition and support.

At all levels, teaching for understanding with an emphasis on science process skills requires a high level of expertise and an appreciation of how science works. Changes in methodology require teacher flexibility and ongoing reflection.

Supports

SLSS Junior Science provides supports for teachers in science process, specific subject areas for non specialists, newer methodologies and using ICT and the internet with students. Face to face, blended and online modules are available. The school visit programme supports teachers working together in collaborative groups in school to address the pedagogical and practical issues which they face. Junior Science assists with issues of transfer from primary to second level and on to transition year or the leaving certificate. Support is available for differentiation and language issues in science.

Discover Sensors is a Discover Science and Engineering (DSE) project which promotes investigative science and appropriate use of ICT. Junior Science collaborates with the NCCA, the NCTE, the Education Centres and DSE in the project. Junior Science also supports the Intel and DSE sponsored SciFest project to promote student investigations which may then be used for the coursework B assessment.

Useful resources are available on www.juniorscience.ie, www.sors.ie and on Junior Science CD / DVDs.

Requests for additional support are welcome and should be directed to sciences@lec.ie

Science Education in Ireland

In Ireland, primary science was introduced in 1999 with the new primary curriculum (DES, 1999). It is recognised as a high quality programme in science with an emphasis on science process skills and investigation. Science at primary level is a spiral curriculum culminating in a programme for 5th and 6th class which is expressed in terms of specified science process skills and several topic strand units. Working scientifically includes questioning, observing, predicting, investigating, experimenting, estimating, measuring, analysing, sorting, classifying, pattern recognition, interpreting, recording, communicating and evaluating.

The revised Junior Science syllabus (DES, 2003) was designed as a continuation from the primary science syllabus and intended to preface a change to the leaving certificate sciences now emerging from the NCCA with consultation expected in 2009. Junior Science was the first syllabus to be written in terms of learning outcomes which specify the knowledge, skills and attitudes which students should attain by the end of the course.

Compared to the detailed specification of content in a traditional syllabus, this gives much greater freedom to teachers and students as to how the outcomes are attained. The syllabus is for integrated science rather than separate courses in biology, chemistry and physics. Practical investigative science incorporating science process skills is explicitly promoted. The preamble also mentions cooperative learning and the use of sensors.

The syllabus includes biology, chemistry and physics plus some climatology and other minor disciplines. The revised syllabus specifies learning outcomes. As an example, the section on animals, plants and micro organisms no longer specifies exactly which organisms need be known and to what degree but rather encourages process skills, such as, "use a simple key to identify plants and animals including vertebrates and invertebrates".

The assessment includes coursework. Coursework A awards 10% for a written record of ongoing practical work spread over three years. It should be available in schools for possible external review over the course of the assessment process. Coursework B awards 25% for a pro forma investigation report submitted together with the written exam paper for correction by the same examiner. Students can select either 2 from 3 set investigations from the SEC each year or a single investigation of the student's own choice.

This provides a further reward for practical work and emphasises the importance of investigative science process skills. All practical work is intended to be done in groups but individual student reports are required. It is intended that students plan and write up their investigations themselves but that teachers provide the framework to develop the necessary skills.

The remaining 65% of the assessment is for a written exam which is intended to assess process skills as well as content knowledge. The assessment has, in effect, adopted a low discrimination policy for coursework while the exam discriminates on evidence of process skills.

Coursework has ensured that almost all students now have a practical experience of science compared with an estimate of one third under the previous syllabus. While the 30 mandatory activities of coursework A is the minimum required, it is expected that, wherever possible, practical exploration will be encouraged and that investigative or problem based learning will infuse the syllabus. It should be set in an investigative context.

The resultant additional burden on teachers encourages a fresh look at the nature of the practical work involved and an impetus to simplify practical activities in the light of technical advances. Examples include simple, inexpensive, dedicated plastic kits for gas preparations to replace the complex apparatus formerly required and plastic A4 sheets for chemical testing rather than glassware which is so difficult to maintain in schools.

A changed approach

How can the rationales, science education research, ICT, learning outcomes and key skills be embodied in science teaching and learning? Taking the learning outcome "plot a cooling curve and explain the shape of the curve in terms of latent heat" as an example, one possible modern approach follows.

Students could be engaged with a focus on a practical application or examples: perhaps a rapid exploration of the effect of perfume on the skin or how sweating can cool the body. The learning intention could then be clearly shared in accessible language. Student cooperative groups could plan briefly how they could explore this by investigation. After discussion of the different approaches proposed, a simple set up with a temperature sensor could be agreed or various possibilities attempted. Student groups could predict what will happen to the temperature of the liquid as it cools. Predictions would be justified in terms of prior scientific understanding. Once agreed, the prediction could be drawn by the students using free graphing software before the investigation is begun.

Example prediction and results are shown in the graph. The focus is immediately on interpretation rather than the mechanics of the experiment and the graphing process. The liquid cools substantially over the course of only 3 minutes. The graph develops in real time. The observations are at odds with the student prediction. There is a clear cognitive dissonance since the (red) measured cooling curve flattens out for some time before cooling resumes. How can we explain that cooling stops and then starts again?

There could be discussion on how suggested explanations might be tested. The melting point of the substance could be located on the internet, the experiment could be run adding a webcam to display, record and synchronise with the temperature measurement. Another experiment could be set up to see what happens as the solid is heated. Further rapid exploration is possible with experimental models of sweating and exploration of evaporative cooling by other liquids.

In further elaboration, students could manipulate free software or real models of the arrangement of particles in solids and liquids. Important links across the curriculum could be discussed. Students could then evaluate their learning. Teacher questioning and feedback are critical. Peer and self evaluation is encouraged.