School Science Education in Wales – A 'Successful Future'?

PROFESSOR DAN DAVIES
Cardiff Metropolitan University

ABSTRACT

This article examines the current state of science education in primary and secondary schools in Wales at a time of significant change in both curriculum and qualifications. It does so against a background of increasing international comparison of pupil attainment and the political imperative for change that perceived weak performance in such measures can create. Whilst reviewing a range of evidence that could be used to judge the effectiveness of science education in Wales, the article also considers the potential impact upon the curriculum of a focus upon 'scientific literacy' in international tests and the likely consequences of current plans to combine science with technology in the curriculum. Centralised reform seldom focuses upon pedagogy, yet the approaches to teaching and learning being adopted in classrooms are arguably more significant than curriculum change. It is therefore salient to review the extent to which research-informed pedagogical shifts in science education are reflected in inspection evidence or guidance. The article concludes with a consideration of the likely consequences of divergence in science assessment and qualifications between Wales and its larger near-neighbour England in the context of a UK-wide higher education marketplace.

Key words: science, international comparisons, curriculum, pedagogy, assessment, qualifications

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Introduction

Science education at primary and secondary level has been the subject of much research, international comparison and curriculum change in recent years. Its curriculum formation, pedagogy and assessment have been scrutinised and reformed in many countries as a result of significant research findings concerning pupils' acquisition of scientific concepts and skills, together with the availability of international comparative data. However, until recently these drivers have arguably had relatively little effect on science teaching in Wales, where in 1999 the newly formed Welsh Assembly assumed responsibility for most aspects of school-level education, with further powers added in 2006. This is about to change. The proposal in *Successful Futures* (Donaldson, 2015) for a 'Science and Technology Area of Learning and Experience' raises the prospect of science disappearing as a named school subject in Wales. Pupils will continue to take GCSE examinations in science (either combined or as separate physics, chemistry and biology) at the age of sixteen, so there will need to be a transition phase at age fourteen where they continue with aspects of science and technology alongside their GCSE studies. However, below this age the elements of knowledge and skills previously packaged as 'science' will find their home – or not – within a radically reconfigured curriculum. Quite what this will look like remains to be seen; whilst *Successful Futures* sets out principles and broad descriptions, it constitutes an emergent model led by 'Pioneer Schools' – 'a network of innovative... schools across Wales who will play a pivotal role in developing and realising the new curriculum' (Welsh Government, 2015) – to gradually add content and detail leading up to full implementation in 2021. Whether a new curriculum developed by schools who have in recent years been pressurised by high-stakes assessment and accountability measures into force-feeding knowledge, 'teaching to the test' and multiple resits can be truly innovative remains to be seen.

The Donaldson reforms have been driven, in part at least, by the widespread perception that the quality of school education in Wales has declined since responsibility for it was devolved to the Welsh Assembly. In particular, international comparisons facilitated by Wales's entry in the OECD Programme for International Student Assessment (PISA) in 2006, 2009 and 2012 suggest that pupil performance in science (as in reading and mathematics) has declined over time and in comparison with other countries within the UK. Welsh pupils' average score in science declined from 505 in 2006 to 496 in 2009 and 491 in 2012, placing Wales equal with Croatia at fortieth position against an OECD average score of 501 (OECD, n.d.). Whilst the validity of such comparisons has been challenged by Rees and Taylor (2014) and other indicators of attainment such as the percentage of pupils achieving A* to C grades in science subjects suggest improvement, the discourse of decline has proved persistent. In anticipation of the publication of results from PISA 2015 – which has scientific literacy as a major focus by contrast with 2012 – now seems a good time to take stock of the teaching and learning of science in Welsh schools and to examine critically the rationale for reform. I will start by examining pupil performance, before considering curriculum, pedagogy and assessment.

Pupil performance in science

As suggested above, the available data on standards of science learning in Wales present a mixed – and sometimes contradictory – picture. The widely publicised PISA results from 2009 and 2012 showed Welsh 15-year-olds slipping from ten to twenty-five points behind their English counterparts and a similar gap open up with Scotland. Rees and Taylor (2014) have argued that some of this discrepancy may be the result of sampling error: for example that a much higher proportion of the total population of schools (and, by extension, of pupils) is sampled in Wales than in England. They further conjecture that since the questions in PISA 'minor domains' (e.g. science in 2012) are optional, projections based on the likelihood of candidates answering missed questions correctly may also skew results. From this perspective, the focus on science in the 2015 survey should provide results with greater validity. The 'PISA panic' occasioned by the 2009 results prompted Leighton Andrews, the then Welsh minister for education and skills, to set a target of Wales finishing in the 'top 20 countries' in 2015; however Huw Lewis, his successor, subsequently revised this to the somewhat more modest aspiration of attaining average scores of at least 500 in reading, mathematics and science by 2021.

The usefulness of drawing comparisons between Wales and the other countries of the UK may be limited by the wider economic and social factors in each country that contribute significantly to educational attainments (Rees and Taylor, 2014). Goldstein (2014) argues that it is just as plausible that it is the lack of experience in taking tests during earlier key stages that explains the gap between the examination performance of

Welsh and English pupils. Estyn (2013: 19), reporting on science teaching and learning in Welsh schools, note that:

> PISA-type questions present pupils with challenges that they normally do not encounter in science lessons in Key stage 3 such as:
>
> - a high volume of reading for understanding, which is generally greater than pupils would encounter in GCSE science questions;
> - the need for pupils to apply their scientific knowledge in answering questions that explore unfamiliar situations; and
> - questions with multiple-choice answers.

Whilst this finding has led to the commissioning of 'scientific literacy' materials for the DfES website to support teachers in preparing pupils for these types of assessment, it further strengthens the rationale for comparing pupil performance within Wales over time rather than against other countries with different systems. With this in mind, the year-on-year rise in the percentage of pupils achieving A* to C grades in science subjects in Wales (up by 1.1 per cent to 70.4 per cent in 2015) appears to contradict the PISA data, as does the outperformance of boys by girls at GCSE – the reverse of the gender gap observed in PISA. Girls also outperform boys at key stage 3, where following a dip in 2007, there has been a year-on-year increase in the proportion of pupils attaining the expected level (level 5 and above) in science (Estyn, 2013). We may conjecture that the discrepancy between PISA (taken at age fifteen) and the key stage 3 (age fourteen) and GCSE (age sixteen) trends is because PISA is measuring different pupil capabilities (as suggested by the description of questions above), which may favour boys. Also, the teacher judgements upon which key stage 3 results are based have come under criticism (see assessment section below). Nevertheless, there are some grounds for hope in secondary school science.

The picture in primary schools is somewhat less positive, particularly with regard to higher-performing pupils. Estyn (2013: 5) report that:

> Until 2010, the proportion of pupils achieving level 5 and above in science was higher than in other core subjects. In 2011, mathematics overtook science as the highest performing subject and the gap in performance between science and English reduced. In 2012, there were no differences in performance in science, English and mathematics. Performance in science at level 5 and above declined steadily between 2005 and 2010. There were improvements in 2011 and 2012, but performance was below that of 2005.

Although Estyn earlier in the same report (p. 2) undermines the reliability of the teacher assessment data upon which such judgements are made, this apparent decline – in comparison with the other 'core' subjects of the primary national curriculum – may be indicative of a wider malaise in primary science education.

The rise (and fall?) of primary science

Since its emergence from nature study in the middle years of the twentieth century and its incorporation into the statutory curricula of many countries around the beginning of the 1990s, primary science has developed significantly in its pedagogy and international status (Harlen, 2008). Since 1989, science has enjoyed 'core' status in the primary national curriculum in England and Wales – designated as such because of its perceived importance to the economy (Coulby and Ward, 1996) – though arguably it has remained a 'core subject' in name only since 2000. Science curriculum time in English primary schools reduced from around 20 per cent to 10 per cent over the 1990s (Ofsted, 1999) and the introduction of national literacy and numeracy strategies further relegated it to an 'afternoon' subject in many schools (Boyle and Bragg, 2005; Blank, 2008). By 2007 science represented just 7 per cent of curriculum time in England (lower after 2010 with the abolition of national testing at key stage 2). Despite this, its status as a core subject in the national curriculum in England was reconfirmed in 2013. In Wales, Estyn (2013) observed that most primary schools devoted between one and three hours of curriculum time per week to science, with a significant minority subsuming it within 'topic work':

> Most of the primary schools visited have placed a low priority on science and have planned few new developments in science over the past few years. This has been mainly because of the greater focus on developing pupils' literacy and numeracy skills. (para. 67)

Further concern about the state of science in primary schools emerges from the work of Shayer et al. (2007), who used one of Piaget's standard tasks to compare 11-year-old British children's developmental understanding of the scientific concepts of mass and volume over a period of thirty years, together with other scientific ideas such as the period of a pendulum or meniscus of a liquid. They found that the performance of both boys and girls on the Piagetian Volume and Heaviness Task had declined significantly from 1975 to 2003, using this to suggest that primary science teaching had become more formulaic and beyond the developmental level of many pupils (Shayer et al., 2007). These findings are echoed by those of Murphy et al. (2011) who suggest that activities are becoming more teacher-led and prescribed, skewing pupils' experience and perceptions of the nature of science.

The hitherto positive attitudes of pupils in primary schools towards science may also be declining. According to the fourth Trends in International Mathematics and Science Study (Martin et al., 2008) children in fourth grade (9–10 years old) had an overwhelmingly positive attitude towards science, with an average of 77 per cent responding at the highest of three levels of the index of Positive Affect Toward Science (PAT) across thirty-six countries (Martin et al., 2008); sadly this had declined to 53 per cent claiming to 'like learning science' in the fifth study (Martin et al., 2012: 344). Although Wales does not participate in TIMSS, a UK-based study by Murphy et al. (2011) indicates that pupil attitudes towards science in primary schools become more negative with age, which the authors suggest may be related to increasingly transmissive teaching styles towards the end of key stage 2.

Arguably the most significant curriculum development in primary science education within the UK in recent years has been the Primary Science Quality Mark (*www.psqm.org.uk/*), an award scheme to enable primary schools across the UK to evaluate, strengthen and celebrate their science provision. Whilst hundreds of schools across England, Scotland and Northern Ireland have gained accreditation for their science work through this scheme, the PSQM is only just getting started in Wales with no awards to date. This and some of the other indications above suggest that – at least at primary level – curriculum reform may be necessary to reinvigorate science education in Wales. However it requires a conceptual leap to arrive at the conclusion that the best thing for primary science is to subsume it within the area of learning and experience of 'science and technology'. We need first to step back and examine the rationale for including science in the school curriculum in Wales in the first place, before going on to examine what form its inclusion should take.

Science in the school curriculum

PISA claims to test the extent to which pupils 'can apply their knowledge to real-life situations and be equipped for full participation in society'

(TUM, n.d.). It calls this set of capabilities 'scientific literacy', which has long been argued as a core rationale for the inclusion of science in the school curriculum (e.g. Millar and Osborne, 1998). Science has become such a dominant part of our culture that, regardless of whether or not we go on to study science at a higher level or go into a science-related career, we all need to have some awareness of 'how science works'– who funds it, what scientists do, how their findings are communicated – to be able to participate as citizens in our society. Roberts (2007) distinguishes between 'scientific literacy' and 'science literacy': the latter referring to an ability to use scientific terms and words appropriately and in the correct context and also 'understanding' scientific ideas. The PISA definition of scientific literacy (TUM, n.d.) is actually closer to what Roberts would call 'science literacy':

- scientific knowledge is applied in order to identify questions, acquire new knowledge, describe scientific phenomena and draw conclusions from evidence;
- characteristics of science are understood as a form of human knowledge and research;
- science and technics are understood to shape our material, intellectual and cultural environment; and
- students are ready to engage with scientific ideas and topics and to deal with them in a reflective manner

The Science National Curriculum in Wales (DCELLS, 2008) already contains requirements for pupils to become scientifically literate, though it is unclear whether this is a principal aim of the curriculum, which is largely skills-based. For example at key stage 2: 'Learners should be taught to relate their scientific skills, knowledge and understanding to applications of science in everyday life, including current issues' (DCELLS, 2008: 10). Whilst at key stage 4, learners are to 'develop their ability to relate their understanding of science to their own and others, decisions about lifestyles, and to scientific and technological developments in society' (DCELLS, 2008: 11). This emphasis remains in the *Successful Futures* proposals for 'Science and Technology', which it is argued contributes to two of the core outcomes for pupils of the proposed curriculum ('ethical, informed citizens' and 'healthy, confident individuals') through: 'evaluating the impact of scientific and technological developments; taking informed personal stances on ethical issues associated with scientific and technological innovation', and 'learning to make use of scientific data to assess risk and take informed decisions'. However, these examples appear to emphasise the understanding of 'how science works' over the application of pupils' own science knowledge (in Roberts's terms above: scientific literacy over science literacy). This does not address Estyn's (2013) criticism of the 2008 curriculum that its lack of defined science content did not prepare pupils well enough for GCSE science syllabuses. Arguably, the 2008 reforms had tried to free teachers from the shackles of a restrictive knowledge-based curriculum and to implement an enquiry approach (at least at key stages 2 and 3), allowing freedom for classroom teachers to develop imaginative, creative learning, based on the clear rationale that skills and knowledge with understanding was as important as accumulating large chunks of knowledge for its own sake. The resultant apparent neglect of conceptual understanding has become the focus of both internal and external criticism.

For there is another, competing rationale for the inclusion of science in school education, which might be called the 'big ideas' argument and which arguably underpins the reformed national curriculum in England (DfE, 2013) through the influence of the American academic E. D. Hirsch on the then Secretary of State for England, Michael Gove. It is claimed that there are some ideas that have been so influential in shaping our society that to deny pupils access to them – through omission or misinformation – is to exclude them from cultural life. Hirsch (1988) would define these as 'core knowledge', which is central to our 'cultural literacy'. An example from science is Darwin's theory of species change through natural selection, which enjoyed its 150th anniversary in 2009. Because it challenges ideas and beliefs about our identity as humans it continues to be as significant today as it was in 1859. The phrase 'big ideas' (so called because they explain a range of related phenomena) was introduced in the *Beyond 2000* report (Millar and Osborne, 1998), funded by the Nuffield Foundation to review practice in science education and how the future needs of young people could best be served. Arguably, the shift away from a core foundation of conceptual knowledge in favour of an 'emphasis on investigative skills in the current science National Curriculum orders introduced in 2008 does not help schools to plan progression in scientific knowledge and understanding' (Estyn, 2013: para. 5), because many had not taken up the opportunity to develop their own schemes of work. It is difficult to see how the curriculum emerging from *Successful Futures* will address this perceived deficit in the previous version.

What the combining of science and technology in the future curriculum may help to strengthen is the economic argument for the inclusion of these subjects: that we need as a society to provide enough new graduates in science and technology to ensure that we maintain industrial competitiveness. Certainly, the success of Wales's education system has been linked in general terms by successive ministers of education to economic prosperity, despite the lack of evidence of a direct link between healthy science education and a healthy economy (Millar and Osborne, 1998). One of the arguments for linking science and technology in schools is that this more closely reflects their mutual interdependence in modern industrialised societies: 'Science and technology are closely linked, each depending upon the other. Science involves acquiring knowledge through observation and experimentation, and technology applies scientific knowledge in practical ways' (Donaldson, 2015: 50). Whilst this combination is relatively new in secondary schooling – Donaldson suggests that it will draw on physics, chemistry and biology, engineering, design and technology, craft, design, graphics and computer science – it reflects an original intention to create a single subject in the primary national curriculum for England and Wales (DES, 1987). This early move was resisted by those who wished to champion design and technology as a separate discipline and not merely an application of scientific knowledge (Davies, 1997). This led to the development of separate subject areas, though more recent reviews of the primary curriculum in England have recommended a joint learning area of 'scientific and technological understanding' (Rose, 2009; Alexander, 2009) before the current version (DfE, 2013) firmly re-established boundaries. The Donaldson proposal for the establishment of a single learning area for science and technology appears to embody a 'Technology-as-Applied-Science (TAS)' model of the relationship (Gardner, 1994) in which science education takes precedence over technological applications of pupils' scientific knowledge. Drawbacks of such an approach include the undervaluing of design skills (Gardner, 1994), which may send the message to pupils that scientific knowledge is more important than technological capability in gaining access to technological careers.

Science is not the only source of knowledge upon which technology needs to draw, and the necessity of children understanding the scientific principles within a technology project is unproven. Gardner argues for an 'interactionist' view of the relationship emphasising the equal and complementary nature of science and technology, which are seen as mutually dependent in some respects yet distinct in others. An interactionist perspective highlights the role of technology in reworking scientific knowledge to make it more 'useful' (McCormick et al., 1995). In a 'constructivist' model of conceptual change (Driver, 1983), technology activities can have a role in restructuring children's scientific misconceptions. Whilst appreciating the differences between processes used in science and technology, it is important in an interactionist model to seek ways in which they can 'feed into' one another. Scientific procedural knowledge (particularly that of designing 'fair tests' as part of investigations) can support the development of design processes. Conversely, the imaging and modelling skills children develop during technological activities can support them in developing mental models and analogies for scientific purposes.

Although students between the ages of fourteen and sixteen will be preparing for GCSE courses in combined or separate sciences, there is still the expectation in *Successful Futures* that they will 'select courses or undertake activities from each of the Areas of Learning and Experience (ALE), hence maintaining breadth and meeting national priorities, including *science* and health' (Donaldson, 2015: Recommendation 31; my italics). The reference to 'science' rather than 'science and technology' here is interesting and perhaps an acknowledgement that, if taking at least two GCSEs in science is to remain compulsory for most pupils, it will be difficult to enforce courses in the more technological aspects of the ALE. Previous attempts to make technological aspects of the curriculum compulsory at key stage 4 have been unsuccessful so the recommendations in *Successful Futures* may experience a similar fate. The trend in GCSE entries over recent years has been away from integration, with the percentage of pupils entered for separate 'triple' science at GCSE doubling to 16 per cent since 2007.

Reforms in Wales from 2016 require almost all pupils to take at least two science GCSEs. This move back to more traditional science qualifications has at least partly been driven by the international comparisons with competitor economies arising from PISA and TIMSS data referred to above, together with a concern that combined science courses did not prepare students properly for A level and beyond. So we can see a tension in the school science curriculum between the integrating move emerging from 'below' (in terms of phase) and the push towards greater academic specialisation from 'above'.

Pedagogy in science education

In 2013, Estyn found science teaching and learning to be 'good or better' in the majority of key stage 2 and 3 classrooms in Wales, but noted very few 'excellent' lessons (Estyn, 2013). So it would appear that the general pedagogical picture is not bad, but the question remains as to what models of pedagogy teachers are using. In the science education research community there has been a paradigm shift in pedagogy over the past fifteen years, though the extent to which this is reflected in teachers' classroom practice – in Wales or elsewhere – is open to question. Since the mid-1980s the dominant model of science pedagogy had been one of conceptual change, sometimes referred to as a 'constructivist' approach. Influenced by projects such as Children's Learning in Science (Driver, 1983) in secondary education and Science Processes and Concept Exploration (Russell and Osborne, 1993), this approach is predicated upon the principle that pupils learn with understanding only if they modify their own naive theories about the world to accommodate the more sophisticated scientific conceptions. The teachers' role is first to elicit pupils' pre-existing ideas and then to provide conceptual conflicts (or cognitive dissonance) between pupils' ideas and scientific evidence. Since the late 1990s, this approach has gradually been superseded by pedagogy grounded in sociocultural theory, which – like constructivism – derives from the work of Vygotsky but accords a much closer relationship between cognition, identity and cultural values (Aikenhead, 1996). Science education from a sociocultural perspective views learning as an apprenticeship (Rogoff, 1990) so that the various psychological planes or dimensions of learning – social, interpersonal and intrapersonal – are not independent of each other. In this tradition, science education can be seen as composed of several intersecting discourses. Pupils can only learn science when they are able to adopt scientific language, values and social norms for the purposes of participating in scientific practices, such as inquiry and application of scientific concepts. Rational argument is not sufficient for pupils to learn this new language – they have to deal with hidden cultural conflicts as well as hidden conceptual conflicts (Anderson, 2007).

The pedagogy associated with a sociocultural view of science education has been termed 'dialogic' by Alexander (2004) to describe a 'genuinely reciprocal' process of communication between teacher and pupil in which ideas are developed cumulatively over sustained sequences of interactions. Alexander makes a distinction between dialogic talk that is 'discussion' which involves shared problem solving and dialogic talk that is 'scaffolded dialogue' in which structured, cumulative questioning leads to 'handover' of concepts. In the field of science education, Mortimer and Scott (2003) have developed a framework for analysing the 'communicative approach' of teachers on two dimensions: contrasting dialogic with 'authoritative' and 'interactive' with 'non-interactive'. They define the four types of communicative approach as follows:

- interactive/dialogic: the teacher and students explore ideas, generating new meanings, posing genuine questions and offering, listening to and working on different points of view;
- non-interactive/dialogic: the teacher considers various points of view, setting out, exploring and working on the different perspectives;
- interactive/authoritative: the teacher leads students through a sequence of questions and answers with the aim of reaching one specific point of view; and
- non-interactive/authoritative: the teacher presents one specific point of view.

A study by Rojas-Drummond and Mercer (2004) found that Mexican primary teachers employing more 'dialogic-interactive' approaches were more effective in developing pupils' learning. However, Mercer and Scott's *Dialogic teaching in science classrooms* project (Mercer, 2007) found relatively few instances of dialogic-interactive approaches in science lessons. This may be taken to imply that dialogic approaches are not particularly prevalent in science lessons in Wales, however some aspects of a dialogic approach (non-directive, taking pupils' ideas seriously) may be inferred from Estyn's highlighting of the following features of what they regard as 'good practice':

> In key stage 3, many teachers give pupils significant freedom to explore open-ended questions such as 'What types of sunglasses are most effective?' or 'Are expensive heartburn tablets better than cheaper versions?' These kinds of questions provide pupils with rich investigative opportunities to develop their scientific knowledge, understanding and skills as well as their skills in writing, numeracy and thinking. Pupils make the greatest progress in their subject knowledge when investigations build systematically on work previously studied. (Estyn, 2013: 9)

Coakley (2011), investigating the introduction of dialogic approaches to science teaching and learning with year 6 pupils (aged 10–11) in a relatively disadvantaged area of inner Cardiff, found that learners' perceptions of themselves as 'talkers' in class and how this contributed to their science learning improved. She also noted an increased frequency of their use of sentences of extended length and of 'exploratory indicator words' (Dawes, 2004) such as if, think and because, suggesting an increasing sophistication in scientific discussion.

A contrasting theme to the 'dialogic move' in science pedagogy is provided by 'direct teaching', which Mortimer and Scott (2003) would probably classify as 'non-interactive/authoritative'. Direct teaching too has its research base, largely provided by Hattie's exhaustive meta-analysis of studies relating to student attainment: *Visible Learning* (Hattie, 2009). Hattie argues that direct teaching 'activates' rather than 'facilitates' learning, characterising the process as follows:

> The teacher decides the learning intentions and success criteria, makes them transparent to the students, demonstrates them by modelling, evaluates if they (the students) understand what they have been told by checking for understanding, and re-telling them what they have been told by tying it all together with closure. (Hattie, 2009: 47)

Its essence lies in clear purposes and success criteria, modelling and practice, and regular and insightful feedback. As such it exemplifies many of the principles of what Black and Wiliam (1998) have described as 'Assessment for Learning' (AfL). Whilst the emphasis upon the formative purposes of assessment – already enshrined in Welsh Government guidance (WAG, 2010) and central to the proposals in *Successful Futures* – may have some echoes in elicitation within a constructivist or conceptual change pedagogy, the emphasis here is more on feedback to the learner than planning future interventions. Direct teaching does not appear to be endorsed by Estyn: in their 2013 science report the only references are to the dangers of 'over-direction' which 'restricts pupils' independence and the development of their ability to plan creatively' (2013: 13). Whilst there are references to the quality of feedback to learners in Estyn's inspection guidance (2015), there is little evidence that Hattie's approach has yet influenced science pedagogy in Wales. Nevertheless, an approximation to 'direct teaching' in the sense of a transmissive pedagogy which pays lip service to an enquiry approach whilst in reality preparing pupils to give appropriate behavioural responses in practical and paper-based tests appears to be prevalent in Wales (as elsewhere).

Assessment

As has been suggested above, the formative purposes of – and teacher judgement in – assessment have been emphasised in Wales to a greater extent than in England, with the assertion that 'an over-emphasis on one focus of assessment, to the detriment of the other, will inevitably be counterproductive' (WAG, 2010: 5). This difference in emphasis is exemplified by the earlier discontinuation of statutory testing in science at key stage 2 in Wales, which had the temporary effect of increasing the amount of enquiry work in year 6 (Collins et al., 2008). Also, unlike England, summative assessment in Wales has focused on pupils' enquiry skills, signalled by the reduction to a single Attainment Target in the 2008 science curriculum by comparison with the four in England.

Recommended practice includes 'teacher commentary on learners' work and peer and self-assessment by learners' (WAG, 2010: 6). Similarly, qualitative record-keeping is suggested with an emphasis on manageability, tacitly recommending avoidance of numerical tracking systems: 'Teachers need to have a manageable way of recording each learner's progress. In most subjects, this is best undertaken as commentary on learners' work' (WAG, 2010: 7). End of key stage 2 assessment 'must include a summative "best-fit" judgement of each learner's performance in relation to the national curriculum level descriptions' (WAG, 2010: 6). In emphasising the holistic nature of such summative assessment, guidance stresses that 'single pieces of work should not be levelled, although they may provide evidence for characteristics from one or more level descriptions' (WAG, 2010: 9). As well as reporting pupil levels in core subjects, schools are required 'to publish their targets for end of key stage attainment for cohorts of learners' (WAG, 2010: 9), which increases the accountability within what might otherwise be seen as a relatively 'light touch' approach to assessment.

There has been a resistance in Wales to the subdivision of national curriculum attainment levels, as had occurred in England:

> Schools should avoid ranking the statements of each level description in terms of perceived demand and/or assigning a sub-level based on a precise number of statements that a learner has demonstrated in his/her work. Similarly, arbitrary sub-divisions within a level are not part of their design or intended use. (WAG, 2010: 10)

However, 'for administrative purposes and as a short-hand communication' schools are allowed to code 'emerging' best-fit level judgements as

X–, X or X+ (effectively a level subdivision). This guidance appears in the section on transition between key stages 2 and 3, suggesting that pressure from secondary schools for finer-grained judgements has led to some weakening of the holistic 'best fit' principle. Primary schools are required to pass on pupil levels with accompanying teacher commentary to secondary schools 'to ease transition'. For core subjects (including science) 'schools should follow statutory requirements for (cross-phase) cluster group moderation, to ensure a shared understanding of standards and the availability of robust assessment information' (WAG, 2010: 11). Hence, moderation is built into transfer arrangements but is not a statutory feature of teacher assessment within schools. This has led to perceived weaknesses in the system:

> There are shortcomings in the assessment of science in nearly all the primary schools and in half of the secondary schools visited … the reliability and validity of teacher assessment in science are doubtful because of the lack of external verification and of clear assessment criteria. (Estyn, 2013: 2)

This may be a coded criticism of the lack of detail in the national curriculum attainment target for science – which would be consistent with other Estyn concerns about the conceptual content (mentioned previously) – adding to the pressures for curriculum reform. However, it may also reflect concern that schools are not using the attainment target to produce their own assessment criteria for science, to support teachers in making judgements on pupil work. Murphy et al.'s study of the perceptions of 1,000 primary and secondary pupils in England and Wales of their science assessment found that, despite being assessed under two different regimes, pupils' views of science assessment appeared to be remarkably consistent:

> Children appreciated the usefulness of science assessment, and tended towards a preference for testing (but not SATs testing) to monitor how well they were progressing and how to improve. There was a largely negative impact of science assessment on children's well-being, however, in both England and Wales (Murphy et al., 2012: 593).

The most popular suggestion (made by 30 per cent of the Welsh pupils surveyed) for 'ideal' primary science assessment was 'frequent, end-of-topic tests', suggesting dissatisfaction with the qualitative forms of teacher assessment prevalent in Wales. Despite this, *Successful Futures* recommends the continuation of teacher assessment as the 'main vehicle for assessment before qualifications' (Donaldson, 2015: Recommendation 39). However, there is the acknowledgement that such assessment will need to take a variety of forms, both qualitative and quantitative: 'Effective systems use qualitative information, such as commentaries from teachers and children and young people, and quantitative information, such as outcomes, grades, levels and that derived from tests' (Donaldson, 2015: 78).

In keeping with the emergent nature of the *Successful Futures* curriculum, the precise details of this mixed economy of teacher assessment will be left to schools to decide; however, they are warned that the frequency of external testing should be 'kept to a minimum'. There are also proposals for a structure of assessment criteria, termed by Donaldson as 'Progression Steps' to be specified at ages 5, 8, 11, 14 and 16 (effectively replacing the current key stages), each of which will consist of a series of 'Achievement Outcomes' for each Area of Learning and Experience. Although we do not have any indication of what Achievement Outcomes will look like, they will embody the principle of pupil self-assessment: 'Drawing on experience in Scotland, Achievement Outcomes will be described from the learner's point of view, using terms like "'I have …" for experiences and "I can …" for outcomes' (Donaldson, 2015: 54). A set of assessment criteria for science and technology specified at three-year intervals will probably not be seen by teachers as sufficient to track learner's progress in either the conceptual or procedural aspects of science. There may be pressure on Curriculum Pioneer Schools and others to develop sets of criteria for teachers (and pupils) to use to track progress between Progression Steps.

As discussed under 'curriculum' above, pupils in the 14–16 age group (there will be no key stages in future) will be preparing for external assessment under the qualifications framework specified by the new body Qualifications Wales. In the case of science, this will comprise the General Certificate in Secondary Education (GCSE) suite of qualifications below:

- Biology
- Chemistry
- Physics
- Science (Double Award)
- Applied Science (Double Award)
- Applied Science (Single Award – not recommended for most students)[1]

It is unclear from *Successful Futures* whether the requirement for pupils in this age group to continue studying aspects of Areas of Learning and Experience will involve a continuation of teacher assessment against

Achievement Outcomes in Science and Technology specified for the age sixteen Progression Step. Given the significance of the GCSE qualification for young people's futures and school accountability it would appear likely that science teachers will prioritise preparation for this external assessment over any internal requirements of the *Successful Futures* curriculum. In the qualifications realm the proposed changes are modest, particularly by comparison with England where the current A–G grading structure is to be replaced by a 9–1 numerical system and controlled assessment of investigative work in science is to be phased out in favour of end-of-course written exam papers. Both of these features of current GCSE qualifications will remain in Wales, where the retention of a single examination board – the Welsh Joint Education Committee (WJEC) – should ensure greater coherence than in the somewhat fragmented and contested qualifications system in England. However, an examination of the previous and reformed GCSE specifications in Wales from 2016 shows that there is little attempt to integrate the sciences in the double award, or to capitalise on and draw together unifying concepts across them. Even 'investigations' are treated separately, since biology, chemistry and physics demand different skills. Given the integrating move in *Successful Futures*, this is perhaps a missed opportunity.

At post-16 level too, Wales is resisting following England's lead by maintaining the General Certificate of Education Advanced Subsidiary/ Advanced (AS/A2) structure as coupled qualifications, with the caveat that the weighting of the AS, as part of the full A level award, is being reduced to 40 per cent. Apart from the withdrawal of AS and A level human biology from 2017 and the boosting of mathematical content, the proposed changes are minimal compared with England. One stand-out feature for A level sciences in Wales is that the practical component will still be assessed and account for part of overall grades, whilst in England practical work will be assessed on a pass/fail basis and not accrue any marks towards the final aggregation. This will potentially create some inequalities within the University and Colleges Admissions Services (UCAS) system, since the higher education sector in England and Wales currently acts as a single market. In future, universities recruiting to science courses would potentially be able to access AS grades for candidates from Wales but not England, for whom GCSE results and predicted grades at A level would be the only available indicator (as was the case before the AS qualification was introduced in 2000). There may also arise a difference in esteem between Welsh and English A levels for university admissions tutors, with the latter potentially coming to be seen as more rigorous as they will be based on two years' study followed by a final examination, despite the increased mathematical content of the Welsh qualifications. If this were to become the case, it would disadvantage pupils in Wales, potentially leading to pressure to reform A levels in line with the changes in England.

Conclusion

Science education – as with every other aspect of schooling in Wales – is about to enter a period of radical change. Whilst inspection evidence suggests that teaching and learning in science is good in the majority of primary and secondary schools – and GCSE results are rising – the perceived weaknesses in teacher assessment combined with declining PISA scores have contributed to a case for change. Whether the proposals outlined in *Successful Futures* (Donaldson, 2015) will achieve the desired changes remains to be seen, particularly as the new Science and Technology Area of Learning and Experience currently lacks content and teacher assessment is to remain the dominant form up to GCSE level. The Donaldson curriculum proposals have nevertheless been widely welcomed and there is certainly a rationale – at least at primary level – for the integration of science with aspects of technology, both philosophically and pedagogically. Scientific literacy as an overriding purpose of science education underpins PISA and is arguably present in the 2008 national curriculum in Wales, where the emphasis on skills has drawn criticism from Estyn (2013) for the lack of conceptual content. Scientific and technological literacy similarly feature strongly in *Successful Futures*, but we might with Roberts (2007) also make the case for 'science literacy' whereby pupils are equipped with key scientific concepts and skills to enable them to make sense of the many sources of information claiming to be scientific that they encounter in everyday life. Science is important because of its 'big ideas' that continue to shape our culture and view of the world, so to deny children and young people access to the excitement and fulfilment that comes with grasping these ideas is to impoverish their education. We must ensure through the transition to *Successful Futures* that curriculum reform is accompanied by pedagogical innovation so that all pupils in Wales have an entitlement to learn and participate in real science.

References

Aikenhead, G. S. (1996). 'Science education: border crossing into the subculture of science'. *Studies in Science Education*, 27 (1), 1–52.

Alexander, R. (2004). *Towards Dialogic Teaching – rethinking classroom talk*. Cambridge: Dialogos.

Alexander, R. (ed.) (2009). *Children, their world, their education: Final report and recommendations of the Cambridge Primary Review*. London: Routledge.

Anderson, C. W. (2007). 'Perspectives on science learning', in S. K. Abell and N. G. Lederman (eds), *Handbook of Research on Science Education*. New Jersey: Laurence Erlbaum Associates, pp. 3–30.

Black, P., and Wiliam, D. (1998). 'Assessment and Classroom Learning'. *Assessment in Education: Principles, Policy & Practice*, 5 (1), 7–74.

Blank, A. (2008). 'Where has the third core subject gone?'. *Primary Science*, 105, 4–6.

Boyle, B., and Bragg, J. (2005). 'No science today – the demise of primary science'. *Curriculum Journal*, 16 (4), 423–37.

Coakley, R. (2011). 'An Investigation into the Impact of the Dialogic Classroom in the Development of More Effective Verbal Interaction between Learners, within Collaborative Group Work and Whole Class Settings, at KS2' (unpublished MA dissertation, Cardiff Metropolitan University).

Collins, S., Reiss, M., and Stobart, G. (2008). *The effects of national testing in science at KS2 in England and Wales*. London: The Wellcome Trust.

Coulby, D., and Ward, S. (eds) (1996). *The Primary Core National Curriculum*. London: Bloomsbury Publishing.

Davies, D. (1997). 'The relationship between science and technology in the primary curriculum – alternative perspectives'. *The Journal of Design and Technology Education*, 2 (2), 101–11.

Dawes, L. (2004). 'Talk and learning in classroom science'. *International Journal of Science Education*, 26 (6), 677–95.

Department for Children, Education, Lifelong Learning and Skills (DCELLS) (2008). *Science in the National Curriculum for Wales*. Cardiff: Welsh Assembly Government.

Department for Education (DfE) (2013). *National curriculum in England: science programmes of study – key stages 1 and 2*. London: DfE.

Department of Education and Science (DES) (1987). *The National Curriculum 5–16: a Consultation Document*. London: Her Majesty's Stationery Office.

Donaldson, G. (2015). *Successful Futures: Independent Review of Curriculum and Assessment Arrangements in Wales*. Cardiff: Welsh Assembly Government.

Driver, R. (1983). *The Pupil as Scientist?*. Milton Keynes: Open University Press.

Estyn (2013). *Science in key stages 2 and 3*. Cardiff: Estyn. Available at: *http://www.estyn.gov.wales/sites/default/files/documents/Science%20in%20key%20stages%202%20and%203%20-%20June%202013.pdf* (accessed 2 February 2016).

Estyn (2015). *Guidance for the inspection of secondary schools from September 2010. Updated September 2015.* Cardiff: Estyn. Available at: *www.estyn.gov.wales/sites/default/files/documents/Guidance%20for%20the%20inspection%20of%20secondary%20schools%20-%202015%20handbook.pdf* (accessed 7 March 2016).

Gardner, P. (1994). 'Representations of the Relationship between Science and Technology in the Curriculum'. *Studies in Science Education*, 24 (1), 1–13.

Goldstein, H. (2014). 'Do league tables really improve test scores?'. Available at: *http://hgeduc.blogspot.co.uk* (accessed 2 February 2016).

Harlen, W. (ed.) (2008). *Science as a Key Component of the Primary Curriculum: A Rationale with Policy Implications. Perspectives on Education 1 (Primary Science).* London: Wellcome Trust.

Hattie, J. (2009). *Visible Learning: A Synthesis of Over 800 Meta-analyses Relating to Achievement*. London: Routledge.

Hirsch, E. D. (1988). *Cultural Literacy: What Every American Needs to Know.* New York: Random Press.

McCormick, R., Davidson, M., and Levinson, R. (1995). 'Making Connections: students' scientific understanding of electric currents in design and technology', in J. S. Smith (ed.), *IDATER 95.* Loughborough: Loughborough University of Technology, pp. 63–7.

Martin, M. O., Mullis, I. V. S., and Foy, P. (eds) (2008). *TIMSS 2007 International Science Report: Findings from IEA's Trends in International Mathematics and Science Study at the Fourth and Eighth Grades*. Boston: TIMSS & PIRLS International Study Center.

Martin, M. O., Mullis, I. V. S., Foy, P., and Stanco, G. M. (2012). *TIMSS 2011 International Results in Science*. Boston: TIMSS & PIRLS International Study Center.

Mercer, N. (2007). *Dialogic teaching in science classrooms: Full Research Report. ESRC End of Award Report*, RES-000–23–0939-A. Swindon: Economic and Social Research Council.

Millar, R., and Osborne, J. (1998). *Beyond 2000 – Science Education for the Future.* London: Kings College London.

Mortimer, E. F., and Scott, P. H. (2003). *Meaning Making in Secondary Science Classrooms*. Buckingham, UK: Open University Press.

Murphy, C., Lundy, L., Emerson, L., and Kerr, K. (2012). 'Children's perceptions of primary science assessment in England and Wales'. *British Educational Research Journal*, 39 (3), 585–606.

Murphy, C., Murphy, C., and Kilfeather, P. (2011). 'Children Making Sense of Science'. *Research in Science Education*, 41, 283–98.

Office for Standards in Education (OfSTED) (1999). *A Review of Primary Schools in England, 1994–1998*. London: The Stationery Office.

Organisation for Economic Co-operation and Development (OECD) (n.d.). *United Kingdom – Country Note – Results from PISA*. Available at:*http://www.oecd.org/pisa/keyfindings/PISA-2012-results-UK.pdf* (accessed 2 February 2016).

Rees, G., and Taylor, C. (2014). *Is There a ‘Crisis’ in Welsh Education? A Review of the Evidence: A Report prepared for the Honourable Society of Cymmrodorion*. Cardiff: Wales Institute of Economic and Social Research, Data and Methods (WISERD).

Roberts, D. A. (2007). ‘Scientific Literacy/Science Literacy’, in S. K. Abell and N. G. Lederman (eds), *Handbook of Research on Science Education*. Mahwah, NJ: Lawrence Erlbaum Associates, pp. 729–80.

Rogoff, B. (1990). *Apprenticeship in thinking: Cognitive development in social context*. New York: Oxford University Press.

Rojas-Drummond, S., and Mercer, N. (2004). ‘Scaffolding the development of effective collaboration and learning’. *International Journal of Educational Research*, 39, 99–111.

Rose, J. (ed.) (2009). *Independent Review of the Primary Curriculum: Final report*. Nottingham: DCSF Publications.

Russell, T., and Osborne, J. F. (1993). ‘Constructivist Research, Curriculum Development and Practice in Primary Classrooms: Reflections on five years of activity in the Science Processes and Concept Exploration (SPACE) project’, in J. Novak (ed.), *Third International Seminar on Misconceptions in the Learning of Science and Mathematics*. Ithaca: Cornell University, pp. 72–93.

Shayer, M., Ginsburg, D., and Coe, R. (2007). ‘Thirty years on a large anti-Flynn effect? The Piagetian test volume heaviness norms 1975–2003’. *British Journal of Educational Psychology*, (77), 25–41.

Technische Universität München (TUM) (n.d.). ‘Scientific Literacy in the PISA study’. Available at: *http://www.pisa.tum.de/en/domains/scientific-literacy/* (accessed 2 February 2016).

Welsh Assembly Government (WAG) (2010). *Making the Most of Assessment 7–14*. Cardiff: Welsh Assembly Government. Available at: *http://learning.wales.gov.uk/docs/learningwales/publications/130425-making-the-most-en.pdf* (accessed 2 February 2016).

Welsh Government (2015). *Pioneer Schools*. Cardiff: Welsh Government.

Note

[1] These will not offer progression routes to AS or A level qualifications in the sciences.