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Physics

Morag Findlay

The history of Physics teaching in Scotland over the last 50 years or so reflects the changes in approach to the curriculum and teaching and learning over that period. The alterations from the introduction of O-Grades in the 1960s to the introduction of Curriculum for Excellence (CfE) in 2004 and new National Qualifications in 2012 via Standard Grades in the late 1980s; the 5 - 14 Curriculum and the Higher Still Programme in the mid to late 1990s, with the first examinations in 2000 (McVittie, 2008, p. 4); reflect a move from qualification for the top 30% of a cohort to qualification for all. The merger of the Scottish Examination Board (SEB) and the Scottish Vocational Education Council (SCOTVEC) to form the Scottish Qualifications Authority (SQA) in 1997 also reflected a concern to provide certification for all pupils, not only those who would go on to university.

As detailed in Chapter 86, the introduction of the CfE programme culminated in the introduction of new National Qualifications to replace the Standard Grade and Intermediate 1 and 2 examinations. With regard to Physics, this process was completed with the introduction of the new National Qualifications Higher Physics examination in 2015 and Advanced Higher Physics in 2016. It is likely that the full implementation of the National Qualifications, the SNP Government's drive to close the attainment gap, and to simplify the National Qualifications point towards the introduction of a new curriculum in the next few years.

The background to Physics teaching currently is the introduction of Curriculum for Excellence (CfE) and the implications which this has had for the National Qualifications. CfE has a focus on active learning (Building the Curriculum 3) which has changed the way Physics is taught by introducing more emphasis on conceptual thinking. Another influence is the ongoing emphasis on formative assessment as an integral component of teaching and learning, a legacy of the Assessment is for Learning programme in the 2000s.

Physics teaching in schools

Physics teachers work in the context of a Science Department or Faculty. A Head of Science is replacing the role of the specialist Principal Teacher of Physics who was responsible for the teaching of Physics. He/she has responsibility for all of the science teaching within a Science Faculty. This may also include responsibility for subjects other than the sciences. A Faculty Head of Science is more likely to be a biology or chemistry teacher than a Physics teacher, based on the typical number of science teachers in a school (see Table 1). As a result, managing curricular change in Physics following the introduction of the National Qualifications is more likely to be distributed among the Physics teachers in a department rather than led by a specialist Principal Teacher of Physics. However, the implications of the change from specialist Principal Teachers to Faculty Heads for the implementation of curricular change are not being reviewed (Brown, 2014).

Table 55.1 Number of Science Teachers in 364 Scottish Secondary Schools from 2008 to 2015. (Source: Scottish Government Teacher Census Data.)

Subject	2008	2009	2010	2011	2012	2013	2014	2015
Biology	1,177	1,177	1,162	1,157	1,169	1,190	1,179	1,165
Chemistry	989	963	936	928	935	935	937	932
General Science	153	137	143	141	143	116	129	128
Physics	887	865	868	850	837	822	823	807

What are the implications of the larger number of biology than chemistry or physics teachers for the uptake of these subjects in schools? Data from the annual Teacher Census showed that in 2015, the average number of science teachers per secondary school was 3.2 biology teachers, 2.6 chemistry teachers, and 2.2 Physics teachers (see Table 55.1). Therefore the average secondary school has one fewer Physics teacher than biology teachers. As a result, it is probable that in most secondary schools, fewer Physics teachers are likely to take science classes in the first two or three years of the

Broad General Education (BGE) than chemistry or biology teachers, with fewer choosing to take Physics as an examination subject as a result. One way to interpret the smaller average number of physics teachers per school than biology or chemistry teachers is that there is a hidden shortage of physics (and to a lesser extent chemistry) teachers. This is likely to have an impact on the uptake of physics, particularly for Higher examinations.

Table 55.2 Number of entries for Higher Science subjects from 2007 to 2016. (Source: SQA Attainment Statistics.)

Subject[1,2]	2007	2008	2009	2010	2011[3]	2012	2013	2014	2015	2016[4]	Mean # of entries /year
Biology	9,169	9,132	9,107	9,308	9,771	9,359	9,935	1,0161	9,739	7,362	9,304
Chemistry	9,490	9,505	9,582	10,179	10,293	10,301	10,356	11,125	10,597	9,862	10,129
Human Biology	3,712	3,755	3,992	4,078	4,269	3,656	3,541	3,449	4,107	5,499	4,006
Physics	8,582	8,765	9,002	9,018	9,447	9,470	9,492	10,071	9,611	9,038	9,250

Notes

1. The table contains the total numbers of Higher entries in a particular year. Revised Highers ran from 2012 – 2015 in parallel with the National Qualification (Higher Still) Highers; the first National Qualification (CfE) Highers were introduced in 2015.
2. 2016 was the first year when only the National Qualification (CfE) Higher was examined.
3. The data from 2007 - 2011 are the number of entries for all centres.
4. The data from 2012 - 2016 are the number of entries for schools.

Table 55.2 shows the number of entries for these examinations from 2007 to 2016. Over this period, the approximate mean number of Higher Biology and Human Biology entries was 13,300; for Chemistry there were 10,100 entries; and for Physics 9,300 entries. Comparing Tables 55.1 and 55.2 shows that there is a correlation between the number of number of science teachers for each subject and the number of Higher examination entries for each subject. This suggests that it may be possible to increase the number of pupils choosing to study Higher Physics by increasing the proportion of Physics teachers in Science Departments so that pupils in the BGE phase are taught by more of them.   This raises the question of how to increase the number of Physics teachers.   Government initiatives to recruit more draw on the existing pool of Physics graduates – who have a wide range of attractive career options beyond teaching. So perhaps one answer to recruiting more Physics teachers is to somehow make Physics teaching a more (financially) attractive proposition.

School Physics

What *is* (school) Physics?   According to Yates and Millar (2016, p. 303) university physicists and school physics teachers in Australia agree that the distinctive characteristics of the subject are "learning a particular form of 'stripping a problem to its fundamentals,' 'using mathematics to solve it,' dealing with the 'fundamental problems of the physical universe'."   It is likely that Scottish physics teachers would have a similar opinion.   These statements are in agreement with some of the rationales for studying Physics in the Course Specifications for the National Qualifications.   For example, the Higher Physics rationale explicitly links learning physics to the four capacities in Curriculum for Excellence, but also 'gives learners a deeper insight into the structure of the subject' SQA (2015, p. 4), which links to the first and last characteristics of physics identified above.   'Using mathematics to solve it' is implicitly one of the aims of Higher Physics as exemplified in the requirement for 'solving problems' in the Unit Specifications.

One of the ways in which physics teachers differ from chemistry or biology teachers is that physics teachers have learned how to 'think like a physicist' (Yates & Millar, 2016) and part of what they teach pupils is how to think in that way.   How does learning to think like a physicist link to the main characteristics of physics identified in the previous paragraph?   More broadly, how does learning to think like a physicist link to one of the perennial debates in education in general and physics in particular about the role of disciplinary knowledge versus skills and processes in education?   The National Qualifications allow pupils to learn how to think like a physicist in several ways: through the use of mathematics in physics; applying physics concepts to problem solving; and the introduction of topics such as the Standard Model of particle physics.

One of the strengths of the subject in Scotland has always been teaching pupils to solve numerical questions. This has been recognised in reports about how well pupils have done in particular examinations, see for example SQA (2016a). This finding is also supported by physics education research (Docktor, Strand, Mestre, & Ross, 2015) which suggests that students are good at numerical calculations, probably because they have been taught which relationship to choose to answer a particular question and drilled in its use. Nevertheless, pupils may find using mathematics in physics difficult because physicists and mathematicians – and by implication physics teachers and mathematics teachers – think about mathematics in different ways (Redish & Kuo, 2015).

The level of mathematics used in physics courses is noteworthy. The SQA policy is that the mathematics used should be at the level *below* the physics being studied. This means that pupils are not hampered learning physics because the mathematics involved is too difficult. Nevertheless, liaison between physics and mathematics departments to ensure that pupils have been taught particular areas of mathematics (such as the use of scientific notation for numbers (MTH4-06b) or the relationship between distance, speed and time (MNU 3-10a)) before the mathematics is used in physics lessons can be challenging.

Conversely, one of the challenges for physics teachers has been helping pupils to *apply* their conceptual understanding to new or unfamiliar situations (Docktor & Mestre, 2014; Docktor et al., 2015). Learning how to solve problems in physics is more difficult than selecting and then using a relationship. Applying conceptual understanding or analysing unfamiliar situations is a perennial challenge for candidates here, see for example SQA (2016a). Docktor et al. (2015) suggest a solution where pupils are taught to explicitly identify the physics principle or concept they will use; justify the choice of this principle, and then plan how they will solve the problem. This approach is broader than picking a relationship and substituting numbers into the relationship because it requires pupils to draw on their conceptual knowledge *before* choosing the correct relationship. This approach is promising, but needs more research.

One of the changes to the new physics courses has been the introduction of topics such as Special Relativity and the Standard Model of particle physics (Higher level) and General Relativity and Stellar Evolution (Advanced Higher level) to enthuse pupils about the subject. One of the challenges of this approach is that it moves teachers away from their comfort zone - preparing pupils to answer numerical questions about physics - to thinking about the frontiers of physics. However, the frontiers are a challenging place to be because the mathematics required to conceptualise, say, the Standard Model of particles is far beyond school level mathematics (Yates & Millar, 2016). As a result, pupils are asked to accept these concepts on the word of the teacher rather than (in theory) being able to check ideas for themselves (for example to confirm that the acceleration of a body is directly proportional to the force applied and inversely proportional to its mass.) This discrepancy raises issues about pupils' understanding of the nature of science and the difference between teaching physics to future physicists and teaching physics to citizens (the majority).

The current curriculum change is the introduction of the National Qualifications National 4 and National 5 to replace Standard Grade and Intermediate Physics and the new versions of Higher and Advanced Higher Physics. This change was completed when the first cohort sat the National Qualification Advanced Higher Physics examination in 2016.

The structure of the documentation for the National Qualifications is complex. Instead of a single Arrangements Document for each course, the Higher Physics documentation now consists of a mandatory Course Specification, Course Assessment Specification and Unit Specifications, as well as Course and Unit Support Notes (SQA, 2016b). The unitary Course and Unit Support Notes contain 'Mandatory Course key areas' as well as 'suggested learning activities' and 'exemplification of key areas' which consists entirely of the relationships which appear on the separate Relationships Sheet for Higher Physics.

One of the ongoing challenges for teachers and pupils with these qualifications is the number of internal unit assessments which must be completed along with an externally assessed assignment and a pass in the external examination to complete the course. The unit assessments are a legacy of the merger of SCOTVEC and the SEB to form the SQA. Pupils need to pass unit assessments for all units and complete a report of an experiment within one of the units to fulfil the internal assessment. In addition, there is a research-based assignment which must be completed in schools and marked externally. As a consequence of the intervention of the Deputy First Minister and Education Secretary, John Swinney, internal assessment will be phased out over the three years from 2016 for all National 5, Higher and Advanced Higher courses, including Physics (Scottish Government, 2016) – see Chapter 68. It is to be hoped that the current review of National Qualifications will streamline the documentation needed for each course as well as removing the internal assessment.

Physics remains one of the most popular subjects in school at Higher level, but there are challenges for all STEM subjects. One of the key approaches suggested by CfE is Interdisciplinary Learning (IDL) which encourages pupils to make connections between two or more different subjects. However, true IDL requires good basic knowledge in each of the disciplines and their different ways of thinking before links can be made.

Earlier, this chapter discussed the difficulties of liaising between Physics and Mathematics departments about the mathematics required for Physics. However, there are also challenges in harmonising the approaches to data analysis among the science subjects, where graphs in physics are typically analysed using a best fit straight line or curve because there is a relationship between the variables; whereas in biology it is often uncertain if there is a link between the variables, and data points are joined with straight lines. This difference can be confusing for pupils, but arises out of the different types of data used in both subjects.

The number of girls choosing to continue with Higher Physics remains less than the number of boys. The National Qualifications have introduced subjects such as Special and General Relativity, the Standard Model and Stellar Evolution which have appeal to both sexes. However, perhaps considering the introduction of topics such as Medical

Physics – which was found as Health Physics in the Standard Grade syllabus – would help to increase the number of girls choosing to continue with the study of Physics.

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