Mathematics and the Secondary Physics curriculum in Scotland

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Introduction

There is a perception that pupils in secondary education in Scotland are less able than they used to be. Empirical evidence is produced in staff rooms and elsewhere that the children aren't as bright as they used to be and that the curriculum has been "dumbed down": the cloth has been cut to suit the needs, as it were. For a 3% mark in 1965, a mathematics student (SEB, 1965) had to be able to:

$$\text{Simplify } (13\frac{3}{4} - 8\frac{2}{3}) \div 2\frac{3}{4}$$

whereas for the equivalent mark, today's student (SQA, 2006) has this:

$$2.73 + 7.6 - 8.4$$

a far easier sum, it seems. For the physics teacher, although "nature ... is written in the language of mathematics" (Galilei, 1623), he is required to describe it in a kind of pidgin mathematics. His students lack the essential nouns, verbs, adjectives and grammar with which to read or write the subject properly. This research will look at how the physics curriculum has developed with its sister mathematics in Scottish secondary education and in particular, the relationship between teachers of Physics and teachers of Mathematics in Scotland. It will try to identify how the subjects articulate together with the intention of providing some indication as to how this articulation may be improved.

Children are becoming less able?

Principal Teachers of Mathematics in Scotland, if they have good record-keeping, have evidence from third-year tests that over the past fifteen or twenty years, children have been getting lower and lower scores in simple numeracy tests. At least one PT Mathematics has suggested that this is proof that children are becoming less able than they were (Anon., 2008a). There are other factors worth examining in light of this empirical evidence, of course, not least being the perception that language skills have evolved in recent years.

The transition from primary to secondary involves a pupil's personal profile record (PPR) being sent on to the high school. The PPR details the pupil's best National Test attainment in each subject in primary. These records are often perceived by secondary teachers, in particular mathematics teachers, as being at odds with the child's actual level of ability in their first year of secondary education. Pupils seem to perform at a lower level than that reported by the primary school. Is it that the primaries – head teachers, perhaps – are falsifying evidence so as to improve their standing with the local education authority? It would be difficult to prove without very rigorous examination of the

national testing done in primary schools. Maybe there is something else at work here. Children move up from primary to secondary at age 11 or 12, depending on when their birthday is, just as they are reaching puberty. Robert Winston makes the connection:

> "Recent studies have even shown that while the frontal lobes go through a rapid spurt of growth up to the age of ten or eleven, they may actually be in reverse during puberty."
>
> (Winston, 2003, p. 208)

Perhaps what is changing is the date of onset of puberty.

The development of the curriculum

The secondary education curriculum in Scotland has been developing against an agenda of social reform under successive political administrations. This has resulted in a lowering of the bar to access secondary education by reducing academic demand. The OECD recognised this in their recent review of Scottish education:

> "Earlier reforms of curriculum and examinations in Scotland succeeded in expanding social access to secondary education. But they did so by differentiating levels of cognitive demand to reduce academic barriers. With higher levels of staying-on now achieved, the national goal is to raise standards of achievement—that is, to increase demands on students."
>
> (OECD, 2007)

The discipline and cognitive demands of numerate subjects seem to have been progressively removed from the curriculum. Current trends in curriculum reform driven by expectations that social inclusion is the paramount objective are continuing this process. In the current review of National Qualifications, the Physics Qualifications Development Team describe the case for review in their rationale and aims document and clearly assert the basis for development of the physics curriculum:

> "Over and above the need to sustain a supply of physics and physics related graduates to the world of work, there is a need to consider the requirements of those who will not go on to study physics after school."
>
> (QDT, 2008)

There is no justification given as to why this need is "over and above" the more conservative or traditional need to study physics, other than a weak connection between the changing needs of society and the need for individuals to be able to make informed decisions, as if somehow a passing knowledge of physics enables citizens to contribute to the decision making process.

The Higher has been referred to as the "Gold Standard" of Scottish Education (see, for example, Hyslop, 2008b) and a comparison of Higher Physics examination questions from 1997 to 2009 might be expected to reflect this. The research might include a comparative analysis of the Higher Physics examinations in recent years to see if language is, indeed, a factor. This year's paper (SQA, 2009), for example, includes a projectile motion question almost identical to one in the 1997 Paper II (SQA, 1997), with an added part requiring students to analyse and articulate reasons for the falsity of a

quoted statement. Both questions carry the same mark but the recent exam reduces the value of the Mathematical Physics elements in order to make room for the explanation.

The generalist approach to defining the curriculum from top-down political agendas by its nature, inclusive of representation of all of the subject areas, could be said to be diluting the influence of the numerate disciplines and in particular physics. This would be very "B Ark" (Adams, 2002) and would result in devaluation of important elements and disciplines only found in the numerate study of science, replacing the objective with the subjective, fact and proof with opinion and being part of a team (LTS, 2007) as the key elements of study.

The question arises of what is the curriculum for. The OECD (2007, p. 18) sets out its priorities for education as firstly:

> "To tackle the environment of poverty and deprivation"

Is this suggesting that the entire structure is built to suit the needs of the poorest extreme of society? They go on to instruct the Scottish Government in 18 recommendations, including scrapping Standard Grade examinations and introducing a generalised Scottish Certificate of Education. The Education Secretary has gone further than this in announcing the end of not only Standard Grade, but also the Intermediate examinations from Higher Still (Government, 2008a). The consultation sets out the priorities in education, firmly placing inclusiveness as the top design principle, above high standards, for national qualifications (Government, 2008b). This is underlined by the government's assertion that:

> "A more successful Scotland can only be created by developing the talents of **all** Scotland's children and young people ..."
>
> (Government, 2008c, original emphasis)

although there is no suggestion that this statement would stand up to any rigorous analysis. The Education Secretary has set out her vision for education in Scotland in context of the Government's five strategic objectives, to build firstly, "A wealthier and fairer Scotland" and lastly, "a smarter Scotland" (Hyslop, 2008a), indicating that politically, fairness is of significantly higher priority than attainment.

The purpose of education and the curriculum

So what is the purpose of the secondary education system and its curriculum? For many, it is the final stage in preparation for adult life. For those who leave school to join the working population by finding suitable work or vocational routes such as the services, sports or business opportunities, it is probably enough. For others who may immediately and thereafter become financial and social burdens for the rest to carry, the relevance of secondary education may pass them by.

At another end of the political spectrum, others hold the academic, perceived to be elitist, view which sees secondary education as part of a process of preparation for life which will normally include undergraduate study. Those who fail to enter university would be expected to follow a career in the clergy or the services.

> "My father decided I was too stupid to do anything else so he sent me to Sandhurst."
>
> (Anon., 1978)

This tension between the contrasting views of secondary education pulls one way or the other according to government policy and the consensus of the political will of those involved in developing the curriculum. In Scotland, this has become very much influenced by an egalitarian social agenda. The present review of the curriculum "A Curriculum for Excellence", begun in 2002, states explicitly the aims of education in Scotland are:

> to enable all young people to become:
>
> - successful learners
> - confident individuals
> - responsible citizens
> - effective contributors
>
> (LTS, 2008a)

and expressly states the purposes of the curriculum:

> "The purposes of the curriculum are to provide the structure and support in learning which will enable [all children and young people] to develop these four capacities."
>
> (LTS, 2008b)

The current physics curriculum

Arrangements for the current Physics certificate courses are learning outcome based, comprising a list of competencies merged with a list of narrowly defined and prescriptive objectives, exemplified by the Higher Physics course specification (SQA, 2004a). These have been produced to be traceable and to offer an almost contractual definition upon which the written examinations are based. Teaching in schools under increasing time and financial pressure tends to regress because of time constraints, lazy teachers or teachers without depth of knowledge of their subject, to "teaching to the test". Resources are produced beginning from the outcomes and going no further.

Curriculum — that which is taught by the teachers — is often distorted by, and limited to, the outcomes defining the course. The Advisory Council on Education in Scotland recognised in 1947 that: ''External examination ... distorts the examined curriculum, depresses the status of the non-examinable and becomes, instead of the means to educational progress, the end itself." (in Paterson (2003, p.2))

It is difficult, especially where sheer numbers and other factors such as poor behaviour in the lower school reduce the teaching time from a nominal (e.g.) 150 minutes per week to perhaps a third of that or less, for the most dedicated and enthusiatic of teachers to engage in the 'non-examinable'. It is possible to identify more opportunities for this higher up the school as the more disruptive element leave school. From a recent Advanced Higher Physics student:

> "...however the qualification never really mattered because what I learned in your class is infinitely more valuable than any grade or mark. Adv physics was the best subject I ever had, no question. What you taught me will help me more than any grade ever could."
>
> (Anon., 2008b)

Frustration is expressed by professional and experienced teachers at the effect on their subject of having the outcomes drive everything else:

> "Finally, don't be put off by the SQA. Their nit-picking, pedantic attitude [...] and their use of misleading and wrong physics [...] can be frustrating and leave you badly prepared for University. Real physics isn't like that."
>
> (Burnett, 2006, p. 3)

although the author seems to have removed this emotive remark in a later version (Burnett, 2007).

One case in point is in the teaching of forces and impulse. Newton's second law is taught in the Scottish secondary curriculum as the direct relationship equation F = ma (SQA, 2004b) but this is an interpretation of Newton II arising from the fact that a proper treatment of rates of change has been removed from the mathematics curriculum and students do not have the mathematics to be able to articulate what a rate of change is. Listening to a first-year lecture by Richard Feynman sums up his expectation at that time that high school students should be easily aware and confident with the differential calculus (Feynman, 2005, for example, Chapter 9). They may be if they have a good grasp of higher mathematics but this occurs too late for physics to make any proper use of it.

It is quite possible that teachers of Mathematics and the developers of their courses believe that their efforts are only frustrated by poor effort, or behaviour, or by children becoming less able. It may be that the curriculum is perfectly adequate to the task of providing a solid mathematical foundation for the successful study of Physics. G. H. Hardy said, "it is undeniable that a good deal of elementary[1] mathematics [...] has considerable practical utility" (1940, ch. 21). It would be interesting to discover how teachers of Physics regard the effectiveness of their Mathematics colleagues or their courses.

The proposed research

> "Ignoramus et ignorabimus"
>
> (du Bois-Reymond, 1880)

There are limits to what can be known: in Mathematics and Physics but even more so in the professional and social interactions between the teachers of these sister subjects. However, it may be possible to examine the relationships amongst and between these two groups to try and discover what might be suggested as changes for improvement in the way they are taught.

> "Wir müssen wissen — wir werden wissen!"
>
> (Hilbert, 1930)

This research will examine and compare how the teachers of Mathematics and Physics in Scotland interact, both within and between the two groups, paying particular attention to the way this has developed with the curriculum in Scotland. Study will have to be made of attitudes and perceptions, often reported, that somehow children in Scottish secondary education are becoming less able; that the curriculum in numerate subjects, specifically physics and mathematics, has been altered to a level

[1] Hardy is using the term "elementary" not in the educational sense, but as understood by a mathematician. He specifically includes integral and differential calculus in this reference.

which can be called "inclusive" of those of lesser ability. Knowledge of the changes in literacy will be required also and the effect these have had on assessment and thereby teaching.

Acquiring such soft social data will require use of interview, survey and perhaps viral methods of data gathering such as are being used by other Ed.D. students[2], although it is recognised that these may impose artificial limitations on the validity of the research due to what Taleb calls the "Anthropic Bias" (Taleb, 2008, p.117), through our presence in the sample.

Richard Feynman (Feynman, 1992) is critical of "Cargo Cult Science" and cites education as an example:

> "There are big schools of reading methods and mathematics methods, and so forth, but if you notice, you'll see the reading scores keep going down – or hardly going up – in spite of the fact that we continually use the same people to improve the methods."

He goes on to say (*ibid.*):

> "A teacher who has some good idea of how to teach her children to read is forced by the school system to do it some other way – or is even fooled by the school system into thinking that her method is not necessarily a good one."

This underlies what I have noticed, coming into education from Industry, that "The System" does not trust teachers to teach: Mathematics departments in particular are often characterised by standardised methods and sequences imposed from without the classroom. This is an area I would like to examine in the research.

Questions

The research will attempt to find answers to a number of related questions. These questions and others are raised in thinking about the project and the answers are expected to inform the conclusions reached.

1. How is the relationship between and amongst teachers of Physics and Mathematics characterised?
2. How is this characterisation reflected in the development of the Physics curriculum in Scotland?
3. What changes in these relationships would be beneficial and how might they be brought about?

Methods

The research will require an extensive review of the literature to identify the facts of how the curriculum has developed and how societal and governmental changes have influenced that development. However, there may be a substantial insight to be had from speaking to those who have been involved in curriculum development in recent years, so a combination of survey and narrative research (Bell, 2007) may be essential.

I expect that I will have to develop a rich picture (Checkland and Scholes, 1990) of Mathematics and Physics education in Scotland and identify areas where the research is going to have scope: to identify the factors which might affect what I am looking at but which are not being studied. This will hopefully give clarity and context to the conclusions. I may have to limit the research to make it feasible. Factors, on first examination, might include:

[2]David Noble's Podcasts (http://booruch.libsyn.com/) and use of Ning (http://edonis.ning.com) are examples

- Literacy trends
- Demands and needs of society
- Economics
- Social welfare and wealth distribution
- Expectations and ethos
- Changes in social behaviours
- Teacher training
- Developments in epistemology / cognitive / psychology / neurology
- Ancient methods of learning
- Teacher dialogue
- Impact of behaviour and classroom management (inclusion)

Data will be sought (by interview and / or structured questioning) from what are often referred to as "stakeholders", not least:

- Teachers
- "Experts"
- Recent school leavers
- Ministers and advisors
- GTCS, LTS
- Journalists and bloggers
- Pupils
- Primary practitioners

Finally

What is it that motivates this proposal? I have noticed that the stereotypical differences between subject teachers in Secondary Education are quite marked. As one who is dual qualified and registered to teacher both Physics and Mathematics, I see these differences reflected not only in harmless caricatures of these professional, but also in the attitudes, experiences and attainment of the pupils who are exposed to them. I would like to understand them and do something constructive to mitigate their negative effects. This research and the journey required to complete it, gives me the opportunity.

References

Douglas Adams. *The Restaurant at the End of the Universe*. Picador, London, 2002.

Anon. quote from a serving army officer. Written on the flight operations room wall, Middle Wallop, Hampshire., 1978.

Anon. assertion made to the author by a principal teacher of mathematics of a scottish secondary school. John Langlands, Glenwood High School, 2008a.

Anon. email from a former AH Physics student, 2008b.

Judith Bell. *Doing your Reseach Project*. Open University Press, Maidenhead, 4th edition, 2007. ISBN 978 0335 21504 1.

P. Burnett. *Advanced Higher Physics Resource Book*. Huntly, Aberdeenshire, 2006.

P. Burnett. *Advanced Higher Physics Resource Book*. Huntly, Aberdeenshire, 2007.

Peter Checkland and Jim Scholes. *Soft Systems Methodology in Action*. Wiley, 1990. URL `http://systems.open.ac.uk/materials/t552/pages/rich/richAppendix.html`.

Emil du Bois-Reymond. Über die grenzen des naturerkennens. In *The Seven World Riddles*. Berlin Academy of Sciences, 1880.

Richard Feynman. *Surely You're Joking, Mr. Feynman!*, chapter Cargo Cult Science, pages 339,340. Vintage Books, 1992.

Richard Feynman. *Feynman Lectures on Physics*. Addison Wesley Publishing Company, 2005. ISBN 0-8053-9045-6.

G. Galilei. unsourced quotation. http://en.wikiquote.org/wiki/Galileo_Galilei, 1623.

Scottish Government. A consultation on the next generation of national qualifications in scotland. Consultation document, Scottish Government, 2008a. URL `http://www.scotland.gov.uk/Publications/2008/06/09084232/0`. Retrieved 10 August 2008.

Scottish Government. A consultation on the next generation of national qualifications in scotland, annex b: design principles for national qualifications. Reference, Scottish Government, 2008b. URL `http://www.scotland.gov.uk/Publications/2008/06/09084232/11`. Retrieved 10 August 2008.

Scottish Government. A consultation on the next generation of national qualifications in scotland, section 1: the case for change. Consultation document, Scottish Government, 2008c. URL `http://www.scotland.gov.uk/Publications/2008/06/09084232/5`. Retrieved 10 August 2008.

G. H. Hardy. *A Mathematician's Apology*. Cambridge University Press, 1940.

David Hilbert. Retirement address. Society of German Scientists and Physicians, 1930. URL `http://math.sfsu.edu/smith/Documents/HilbertRadio/HilbertRadio.pdf`.

Fiona Hyslop. Keynote address to scottish government international summer school on school leadership. Web page, July 2008a. URL `http://ltsblogs.org.uk/cpdteam/2008/07/30/fiona-hyslops-speech-in-full/`.

Fiona Hyslop. Speech at the ssta 64th annual congress. In *Keynote*. SSTA, 2008b. URL `http://www.scotland.gov.uk/News/This-Week/Speeches/smarter/ssta`. Retrieved Tue 4 August 2009.

LTS. Draft experiences and outcomes for science. Web page, Learning and Teaching Scotland Curriculum Review Group, 2007. URL http://www.ltscotland.org.uk/curriculumforexcellence/outcomes/science/index.asp. Retrieved 10 August 2008.

LTS. What is curriculum for excellence. Web page, Learning and Teaching Scotland, 2008a. URL http://www.ltscotland.org.uk/curriculumforexcellence/whatiscfe/background.asp. Retrieved 10 August 2008.

LTS. What is curriculum for excellence, the purposes of the curriculum 3 – 18. Web page, Learning and Teaching Scotland, 2008b. URL http://www.ltscotland.org.uk/curriculumforexcellence/whatiscfe/purposes.asp. Retrieved 10 August 2008.

OECD. Reviews of national policies for education - quality and equity of schooling in scotland. Executive summary, OECD, 2007. URL http://www.oecd.org/dataoecd/59/22/40328315.pdf. Retrieved 6 August 2008.

Lindsay Paterson. *Scottish Education in the Twentieth Century*, chapter 1. Edinburgh University Press, 2003. ISBN 0 7486 1590 3.

QDT. Physics qdt rationale and aims document. amended January 23, 2008, Scottish Qualifications Authority, 2008.

SEB. *Arithmetic Ordinary Grade paper*. Scottish Examinations Board, 1965. Scottish Certificate in Education examination.

SQA. *Physics Higher Grade, Paper II*. SQA, 1997.

SQA. *Physics Higher National Course Specification*. Scottish Qualifications Authority, sixth edition, 2004a.

SQA. *Standard Grade Arrangements in Physics*. Scottish Qualifications Authority, 2004b.

SQA. *Mathematics Standard Grade General Level Paper 1*. Scottish Qualifications Authority, 2006. National Qualifications examination.

SQA. *Physics Higher Paper*. SQA, 2009.

Nassim Nicholas Taleb. *The Black Swan*. Penguin, 2008.

Robert Winston. *The Human Mind*. Bantam Press, London, 2003.