1. The Royal Society of Edinburgh (RSE) greatly welcomes the review process initiated by the *Curriculum for Excellence* and the opportunity to comment. The RSE initially sought to comment on the draft experiences and outcomes for numeracy, mathematics and science in line with the feedback period for these subjects. In this context, the RSE convened an expert working group consisting of senior Fellows from these disciplines as well those with a background in educational policy and teaching, led by the General Secretary, Professor Geoffrey Boulton. However, it is important to note that the RSE working group's concerns about the process and its outcomes led it to consult with specialists from other curriculum areas as well as other learned organisations in order to explore whether the group's concerns resonated with others. They did. This paper should be read in that wider context.

2. Science has changed, is changing and will continue to change the way in which we live and is a key tool in global and national attempts to achieve sustainability. It is crucial that Scotland is able to develop both practising scientists able to contribute to these developments and a population able to understand and help govern them through democratic processes. Mathematics and numeracy are vital in supporting these aims and in providing part of the skill-set needed for everyday life. The school curriculum, the schools and their teachers are the fundamental bedrock on which much of this rests. It is in this context that we respond to the consultation on science, mathematics and numeracy.

3. We welcome the aims and values of the *Curriculum for Excellence and,* in the context of science, the intention to develop cross-cutting, interdisciplinary themes "drawing together outcomes from one area of science with another"; the concern with applications and real world relevance; and the focus on active learning in open ended investigations, together with discussion, debate and critical thinking. However, we have three major areas of concern which, if not addressed, will undermine the potential of a new curriculum. They are addressed below.

The role of the disciplines

4. There appears to be no recognition in the documentation that there is a structure to human knowledge that has been built up over centuries, and is the means by which we understand the world around us and ourselves. In the last two centuries, the evolution of disciplines has been the means whereby the nuts and bolts of reality have been analysed and understood. They are still powerful drivers of new knowledge. This has three implications for the current process of curriculum development:
   - Firstly, the "outcomes" do not contain this knowledge, and cannot alone be used to develop a curriculum. There must be an interplay between discipline-based knowledge and desired outcomes if a coherent and effective curriculum is to be developed. The current curriculum matrix confuses outcomes, with syllabus and recommendations for teaching method. Within modern educational thinking, all these are important but not interchangeable.
   - Secondly, cross-disciplinary understanding will lack rigour and utility if it is not part of a structure in which the disciplines are columns with cross-disciplinary work, best developed through issues and applications, as the lintels. Without the columns, the lintels fall.

- Thirdly, the statements of experiences and outcomes contain hardly any mention of fundamental concepts, laws and methods. Where will the bedrock of understanding come from whereby the next generation of scientists or even of scientifically aware lay-persons will be developed? Competence requires deep foundations of experiment- or experience-based knowledge within a logical conceptual framework. In mathematics, the "outcomes" are all about consequences of mathematical learning, not about learning mathematics. Numeracy, is not defined in the document, nor how its content will be determined. In science, the outcomes emphasise applications, ethics and the philosophy of science at the expense of fundamental principles. How and where will science be learned?

5. Many of us have been deeply involved in and strongly support efforts to create the greater cross-disciplinary understanding that the modern world needs. In achieving these aims, it is crucial to encourage and create teaching opportunities that break down the barriers that frequently exist between traditional subjects and their teachers. We applaud the *Curriculum for Excellence* in its aspiration to do this. However, we are also aware of the dangers of casting off the disciplinary frame on the assumption that an entirely cross-disciplinary structure of understanding exists that can readily form the framework for learning. Many powerful cross-disciplinary syntheses have been forged from deep disciplinary awareness, between, for example, mathematics and computing or psychology and genetics. In a similar way, psychological research suggests that coherent disciplinary frameworks support the learning process and can also be creatively articulated as pillars of cross-disciplinary understanding.

Developing and implementing a curriculum

6. It is intended that trials of the draft experiences and outcomes will be run by Learning and Teaching Scotland in collaboration with schools and education authorities. For the reasons given above, we are highly sceptical that the experiences and outcomes could be productively absorbed into the curriculum, as appears to be intended, without a major conceptual effort. If, however, a new curriculum is to be produced, the current documents provide an inadequate framework for doing so. Very substantial further work will be required if the outcomes are to be made compatible with the structure of knowledge as it exists or is likely to develop, and if the deliberations of the separate teams that have been working on 3-15 outcomes and the new 15-18 structures are to be brought together. It would also be helpful to know, for example, what examination questions would look like at level 4 and above, not because a curriculum should be driven by assessment, but because well-designed examination questions make precise the necessarily general statements of intent in a curriculum policy. If major curriculum development is required of local authorities or schools, it would be a major, resource-intensive task, involve excessive duplication and have the potential for a confused and confusing curricular structure across Scotland.

7. We regard the issues in paragraph 4 to be of fundamental importance in developing a curriculum, but recognise that the Scottish Government is unlikely to want to restructure the process in its entirety. A way forward from an unsatisfactory position might therefore be to re-engineer the process by developing two strands of activity. The first would be to exemplify how outcomes could translate into real learning tasks. The second would be for a team of teachers and other educators to create documents that offer guidance to teachers on logical conceptual frameworks that could link outcomes to a stronger learning journey.

8. There is a real need for transparent national leadership in the exercise. *Curriculum for Excellence* suggests a greater extension of school autonomy, with a move towards a more flexible system in which schools and teachers have significant input into the direction of learning, which we welcome. However, we have grave concerns that, if not properly worked through, it could lead to different agendas being set in schools throughout Scotland. There is a pressing need for continuity in the curriculum and a common experience for all users. The development of common understandings of the structure and details of a curriculum is not the same as centralisation of control of the curriculum. A consensus could be reached by teachers of each specific subject, consulting with disciplinary experts from other sectors such as universities, research institutes and business. Government and its agencies, however, do have a role in encouraging the development of these common aims.

Implications for the teaching profession

9. The OECD Review[1] noted the high degree of dedication and proficiency of professionals in the Scottish school education system. Teachers are a key priority for a successful education system. Teaching effectively requires the prior deep knowledge of a discipline, of the skills associated with it, of the characteristic pedagogy of the discipline and of the cognate areas of knowledge that are typically introduced at each stage of learning. However, current debates about schooling appear to dismiss such expertise as no longer particularly important, allegedly generic teaching skills being given far greater prominence. Indeed, the current proposals appear to devalue expertise (the proposals for science for example would potentially give as much opportunity for "creation science" as for natural science).

10. The aim that "all science staff look for opportunities to develop and reinforce science knowledge and skills within their teaching activities and work with their colleagues in other subjects to plan inter-disciplinary studies and a coherent approach to the development of literacy and numeracy skills, and to themes such as citizenship or enterprise" is encouraging, but will require an unprecedented cultural change in the teaching profession. This challenge will not be met without a major injection of support and resource.

11. Although the curriculum is important, an excellent cohort of teachers is arguably more important. It is vital therefore that the current process of curriculum development neither alienates teachers because of their distance from the process (and after all, they are the experts), nor imposes an oppressive burden of implementation on them. We would argue that an equally important current priority should be to review implementation of the McCrone proposals, which, had they been implemented fully, could have had a major impact on Scottish education. If a common understanding of each curricular area is to be developed by teachers themselves, then a great deal more time and resource must be given for the continuing professional development of teachers in their areas of disciplinary expertise and in fostering of interdisciplinary working. This renewal and enhancement of subject skills for teachers should have equal prominence with the welcome new opportunities which have been provided for the development of pedagogical and management skills.

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[1] Reviews of National Policies for Education – Quality and Equity of Schooling in Scotland, December 2007.

Additional Information and References

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A detailed analysis of the proposals for mathematics, numeracy and science is contained in an appendix.

Copies of the response can be requested from the RSE's Consultations Officer, Mr. William Hardie (email: evidenceadvice@royalsoced.org.uk). Responses are also published on the RSE website (www.royalsoced.org.uk).

The Royal Society of Edinburgh, Scotland's National Academy, is Scottish Charity No. SC000470

April 2008

Appendix

Comments on the science, numeracy and mathematics guidelines in *Curriculum for Excellence*

This Note offers some comments on the proposals for 'mathematics' (section A), 'numeracy' (section B) and 'science' (section C) that have been issued as part of the debate about the Scottish school curriculum. The comments draw upon the current consensus of conclusions from research on learning, which are summarised in section D. The over-arching comment is that the proposals pay inadequate attention to the important disciplinary base of sound learning.

(A) Mathematics

(A1) General approach and 'Covering paper'

(A1.1) There is barely any mention of fundamental concepts, laws, methods of operation, etc. The 'outcomes' are all about consequences of mathematical learning, not about learning within mathematics. The latter is merely presupposed, but where, then, is it to take place? For example, where would technical details of algebra be introduced and developed? How far should algebra be developed at each age? What kinds of algebraic skills would be required at the final level in this document as pre-requisites for effective learning at Higher Grade level? It would be impossible to answer any of these kinds of question from this document.

(A1.2) In particular, there is no mention of developing the concept of proof. This would not be appropriate in the earlier stages of schooling, and would not be fully developed at any of the stages covered by this document, but some basis for its later development ought to be laid. 'Proof' is such a fundamental concept that it would be difficult to see how the proposals could be described as a truly 'mathematical' syllabus if it were wholly absent.

(A1.3) Claims are made in the 'Covering paper' for the capacity of mathematics to develop 'logical reasoning, …' etc in general. What is the evidence?

(A1.4) It is claimed in the 'Covering paper' that 'mathematics is important in everyday life', and yet in the numeracy paper mathematics is implicitly defined as that which is not useful in everyday life: see the section in the numeracy paper headed 'The connection between numeracy and mathematics outcomes'.

(A1.5) The areas in which, in the mathematics 'Covering paper', mathematics is claimed to play 'an important role' do not include 'social science', or what might be better called ‘citizenship’ – eg interpreting statistical information about the economy. This is an odd omission.

(A1.6) In what sense ‘should’ young people ‘experience success’, and in what sense should that be ‘without fear of being wrong’? If the ‘should’ is normative, then on what grounds? If it is based on evidence that such experiences are more conducive to sound learning than other kinds of experience, then what is the evidence?

(A2) Some more detailed comments on Mathematics ‘outcomes’, as examples of what is weak about the proposals

(A2.1) Outcome MNU406H (at fourth level on page 5).

What is meant by ‘the most appropriate form of fractions’? The answer might vary according as the context was in mathematics, in computations by hand, in computations electronically, in science, or in everyday life. Perhaps all of these (and others) are meant, but what is then missing is any attention to the underlying, essentially technical competence of being able to handle fractions, being able to convert from one form to another, and being able to communicate the results neatly and logically. Premature attention to ‘appropriateness’ might prevent these technical skills’ being acquired.

(A2.2) Outcome MTH310H (at third level on page 5).

Pictorial methods may be fine heuristically, but nowhere is there any outcome that specifies that the student should develop an awareness that pictures might be misleading, precisely because they might miss a physical instance of a general concept that is counter-intuitive.

(A2.3) Outcomes MNU409K (fourth level, page 6) and outcome MTH417N (fourth level, page 8).

Why do some outcomes specify some ethical aspect of learning (such as the first one here – ‘responsible lifestyle’), while others do not (such as the second here – merely ‘applied in the workplace’, with no values specified)?

(A2.4) Outcome MTH326W (third level, page 14).

Bias cannot, as such, affect reliability (although it might affect our estimates of reliability). And what, precisely, is meant by ‘results are unprejudiced’?

(A2.5) Outcome MTH433W (fourth level, page 14).

Neither here nor elsewhere in this section on ‘data and analysis’ is there any consideration of validity. For example, there is no suggestion that students might conclude that none of the mean, the median or the mode provides a valid summary. Moreover, the range is not an average, and its inclusion here is therefore confusing.

(B) Numeracy

(B1) General approach and 'Covering paper'

(B1.1) Points (A1.4) and (A1.5) on mathematics are relevant here too.

(B1.2) Under 'implications for schools'.

Given the importance being attached to the value of numeracy in everyday life, why does the bulleted list of 'successful practice' (by schools) not include consultation with, eg, employers to establish what would actually be valuable in the workplace, or systematic attempts to obtain information about those aspects of pupils' lives in which they might need numeracy skills (as opposed to what adults think might be relevant)? (The mention of 'children and young people' here is in connection with evaluating effectiveness, not with defining outcomes.)

(B1.3) There is in fact no definition of numeracy anywhere in the document, and so its systematic development is difficult to plan. This is different from 'mathematics', which is also not defined in the documents, but which could be taken to be defined by the body of knowledge called by that name.

(B1.4) One cannot see how the distinction between 'numeracy' and 'mathematics that is not numeracy' could be coherently maintained. For example, one doubts if the example in Appendix 2 ('sports day') could be handled without such mathematical concepts as: whole numbers, fractions and their relationship to portions of things, combinatorics (for money changing), or geometrical shape (for mapping out the track). Maybe the authors of the document would include such concepts in 'numeracy', but one doubts it; and then how would pupils begin to develop a sense of the wider mathematical frameworks in which they are embedded?

(B1.5) A specific instance of the point in (B1.4) is under 'The connection between numeracy and mathematics outcomes', where it is claimed that, although fractions as such are 'numeracy', adding or subtracting fractions are not. One finds that bizarre, and also inexplicable in the context of the example mentioned in Appendix 2 ('sports day').

(B1.6) One would make the same comment as in (B1.5) on the claim that 'making statistical calculations' is not an everyday activity. Informally, that would simply not be true: we spend a lot of time informally estimating quantity (eg vehicles waiting at a junction or people waiting in a queue), or assessing risk (eg paying a credit-card bill as opposed to taking out an overdraft). Many people also regularly do specifically statistical kinds of calculation too, such as in relation to the results of sporting events.

(B2) Some more detailed comments on Numeracy 'outcomes', as examples of what is weak about the proposals

(B2.1) The comments in (A2) under Mathematics are relevant to some extent here too.

(B2.2) Outcome MNU401A (fourth level, 'estimation and rounding').

‘Inaccuracy’, ‘error’, ‘tolerance’: the sharp distinction being drawn here is not clear, and so it is difficult to assess what is meant.

(B2.3) Outcome MNU408J (fourth level, ‘fractions, decimals …’).

Given the recurrent emphasis on real-life problems, why is there (here or elsewhere) hardly any mention of the capacity to formulate problems mathematically (not only solving them)?

(B2.4) Outcome MNU314L (third level, ‘time’).

This example is so simplistic as to belie any claim to being about ‘real life’: it’s akin to the old problem of the time taken to fill a bath with the plug out.

(B2.5) Outcome MNU432W (fourth level, ‘data and analysis’)

There is no mention of the need to justify objectively ‘relationships I observe’.

(B2.6) Outcome MNU435Y (fourth level, ‘ideas of chance…’)

The mantra (from the parallel policies entitled *Assessment is for Learning*) that all outcomes have to be expressed in the form ‘I can …’ has led here to the potentially erroneous confusion of the technical term ‘expectation’ with the common-sense concept ‘expect’. An understanding of probability will not tell us what to ‘expect’, although it might tell us what the ‘expected value’ is. Consider an obvious example. Denote by Y the random variable counting the number of children in a family (‘family’ defined, say, in the standard way used by the Census). If you select one family at random from the population of Scotland, the ‘expected value’ of Y is about 1.8. But in no sense do we ‘expect’ that family to have 1.8 children: ‘expect’, in this everyday sense, relates far more to the mode than to the long-run mean.

(C) Science

(C1) General approach and ‘Covering paper’

(C1.1) As with both mathematics and numeracy, there is scant mention of fundamental principles, laws and techniques. Knowledge of these is presupposed in the outcomes listed here, many of which are not, in fact, scientific at all. So where are the basic ideas of the various branches of science to be taught, and how might we be assured that pupils will emerge from their school years having had some opportunity to grasp these?

(C1.2) The document conflates science with the ethics and philosophy of science. For example, in the first bulleted list in the document called ‘Engagement process’, the last three items are not scientific outcomes at all. To put this starkly: if we allow that ethical debates (etc) are part of the scientific curriculum, then how do we prevent ‘intelligent design’ or creationism being insinuated into the science curriculum? Ought not the debate about such matters be taking place elsewhere in the school curriculum, for example under the heading of Religious and Moral Education, or Media Studies, or in parts of the Geography, Modern Studies or History curricula?

(C1.3) The recurrent emphasis on the role of ‘investigations’, while unobjectionable in itself, tends to set aside the importance of rigour, either theoretical or empirical. The full development of such methodological concepts might not be attainable during the age range covered by these proposals, but some foundation should be laid, and the best students (gaining a level 1 at Standard Grade) ought to be familiar with such ideas as: what counts as a well-conducted experiment? how might the data from field observations be organised systematically? and how are scientific laws abstracted from experiments and observation?

(C2) Some more detailed comments on Science ‘outcomes’, as examples of what is weak about the proposals

(C2.1) Outcome SCN402A Chem, fourth level (‘sustainability’, page 1)

The bringing together of two quite different kinds of knowledge (of ‘extraction of metals’ and of ‘ethical issues’) is liable to confuse the learner, mixing up different kinds of evidence, different kinds of logic, and different kinds of implication. For example, the science of mineral extraction might be perfectly sound, but the ethics questionable; or an ethically defensible plan of extraction might yield ore that was unusable. Trying to teach two such disparate outcomes under one heading risks pupils’ understanding neither very well.

(C2.2) Outcome SCN407B Bio, fourth level (‘biodiversity’, page 2)

Similar point to (C2.1): how science ‘can’ be used is conflated here with how it ‘ought’ to be used. Knowledge of the former is a valid educational outcome in itself, and is not dependent on the capacity to understand the latter. For example, understanding the science of genetic modification, and how it relates to traditional plant breeding, is an independent outcome which can be achieved regardless of whether someone is or is not adept at discussing the ethical issues.

(C2.3) Outcome SCN310G, third level (‘energy sources’, page 6)

This is another example of the same point. Optimising the output of an energy-generating device is an important question of applied physics. Understanding this is not the same as, and is potentially confused by, the equally important but quite separate matter of its ‘commercial potential’.

(C2.4) Outcome SCN444BB All, fourth level (‘forensic science’, page 17)

There is no (or not necessarily any) science in this outcome at all. For example, suppose the ‘scientific theme of topical interest’ was the use of stem cells for medical experiments. It would be possible to ‘analyse the issues’ without knowing more than fairly general things about the technical scientific aspects of this question.

(D) General points about research on how children learn

The comments in sections A, B and C above draw upon what is known about the role of disciplinary learning, the research consensus on which may be summarised as follows:

(D1) For each individual learner, new knowledge has to be actively constructed from existing knowledge. That is what 'student-centredness' means, and is now well-established in at least half a century of research. To that extent, the approach taken by the documents is reasonable.

(D2) However, that existing knowledge need not be the learner's own actual knowledge, contrary to the assertions of the most extreme (and currently dominant) versions of student-centredness. It would, for example, be a waste of time and wholly discouraging to students to expect them each to re-construct 2,500 years (or even the last 50 years) of mathematics. The key here is Vygotsgy's idea of the 'zone of proximal development'. A useful metaphor is this. The learner is placed on a path of learning by a wise teacher. The teacher can see over the horizon to the landscape which comes next on the path, but the student can't. So the teacher, acquainted with the landscape of knowledge, is the indispensable guide to the student. But (in conformity with (D1)) it is the student who does the actual work of making progress along the path. Further comment on the role of the teacher is below ((D5) to (D7)).

(D3) To develop competence in any subject, the student must acquire: (i) a deep foundation of factual knowledge; (ii) an understanding of facts and ideas in the context of a conceptual framework (what we call a 'discipline'); (iii) a mental organisation of that knowledge that facilitates retrieval (a second function of disciplinary organisation).

(D4) Meta-cognition helps students acquire these things: eg setting their own goals, and monitoring their own progress towards these. That is what active learning entails. But to be able to do that requires that the student has already grasped the norms and methods of enquiry specific to the discipline in question. For example, it would be all but useless to monitor one's developing understanding of a field of literary enquiry by the criteria that might be invoked for monitoring mathematical learning. In literary studies, there would be few absolute certainties, no concept of 'proof', and correspondingly a need to understand one's emotional responses. In contrast, the learner in mathematics will get nowhere without a concept of proof, and of indisputable knowledge, and has to learn that aesthetic concerns in mathematics are of a second-order kind compared to their fundamental importance in literary criticism. There are, in short, very few truly generic skills other than quite trivial ones.

(D5) The role of the teacher, with expertise in the landscape of knowledge suggested in (D2), is therefore crucial. It seems from the research that one important role is indeed 'teaching by telling', what we might call lecturing, once the student has been led to appreciate that there are dilemmas which need to be resolved. For example, suppose the student has already appreciated that there is a puzzle about how bread is made, and has already asked questions such as: why does the dough rise? why does it sometimes not rise? why does the bread sometimes have little holes in the middle? why does bread have to be baked at a much higher temperature than vegetables? At that moment, didactic lectures on fermentation, carbon dioxide, gluten and elasticity by (disciplinary) experts are precisely what are needed. In the absence of such previously formed questions, such lectures might indeed seem dry and not an effective source of learning, but the key point is that students would not, on their own, be able to answer the questions, and so that the didacticism of the expert is required to advance such understanding.

(D6) Teaching effectively requires the prior deep study of a particular subject area: it requires knowledge of a discipline, of the skills associated with that discipline, of the characteristic pedagogy of the discipline (so-called 'pedagogical content knowledge'), and of the 'zone of proximal development' (see (D2)) that typically appears at each stage of learning. However, in current debates about schooling, such expertise is no longer seen as being particularly important, allegedly generic teaching skills being given far greater prominence.

(D7) One implication of (D5) is that teaching in depth often requires that programmes of study be designed over a whole year, or over several years. 'Modular' structures make that very difficult.

(D8) It is then clear in a more general sense that continuing attention needs to be given to maintaining the disciplines and to maintaining the pedagogy of each discipline. Although that is hardly the concern of most teaching (even at university level), any pedagogical practices that don't allow for that to happen somewhere, and at some level, will, in the end, erode the disciplinary basis on which all sound learning is based. What that means is that, even at school level, there have to be opportunities for some students to develop a specialist interest of a specifically disciplinary kind: there have to continue to be opportunities for deep learning by the minority who will eventually take that discipline forward in the next generation. Such opportunities should, so far as is practicable, be available in all schools, because this emerging passion for a subject cannot be predicted in advance or confined to pupils in particular schools. Of course, greater use of shared advanced teaching between schools (perhaps using electronic technology) might help here.