The School To University Transition In STEM Subjects

Final Report

February 2005

A project formulating advice from the university academic community across Scotland

linked to the Deans of Science & Engineering in Scotland

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EXECUTIVE SUMMARY OF KEY FINDINGS

The project has involved discussions with almost 200 individual academics, across all of Scotland's 13 universities. There is a remarkable degree of consensus in their responses to the issues probed by the project, with the same views emerging independently in very many different individual interviews and discussion groups. The Deans of Science & Engineering in Scotland have discussed this project and have registered their agreement with the conclusions reached.

Summary of conclusions

1. We believe that a fundamental and comprehensive review of the science curriculum is needed, and we greatly welcome the priority given to addressing science education under the Review process initiated by the publication of *"A Curriculum for Excellence."*

    - The *Curriculum for Excellence* principles, which emerged as our own work was nearing completion, appear to us to be remarkably compatible with, and in sympathy with, our own recommendations for STEM (science, technology, engineering and mathematics) subjects.

2. We have great respect for the commitment and professionalism of science teachers in Scottish schools and acknowledge the pressures under which they work. We are aware of the huge efforts which are exerted to ensure that science courses are robustly specified and assessed. We do feel, however, that the science curriculum itself is seriously out of kilter with modern requirements. We are concerned about:

    - negative trends in uptake in science and technology subjects in the upper secondary, and the difficulty in attracting applicants to university courses, particularly into physical sciences, engineering and computing science;
    - the degree to which curricula are topic-knowledge dominated and assessment driven;
    - the very limited extent to which the relevance of science to modern life, and the nature and importance of science 'issues,' are brought out and
    - 'disconnects' in the progression of science education, such as between primary and secondary, and in the marked increase in difficulty, relative to other subjects, between Standard Grade and Higher.

3. It is very important for school science to attract and prepare the very significant proportion of young people who will become future professionals in STEM areas or members of a technically skilled workforce. It is also, however, vital to ensure that the future population as a whole has a broad understanding of the significance of science and can assess intelligently the public policy issues and dilemmas which must be resolved in funding and regulating science. We strongly believe that any review of the school curriculum should embrace this full range of national needs. Even taking a narrow perspective of the direct interests of university academics in STEM disciplines, a well developed understanding of the contemporary significance of science is important both for our student entrants and for the wider population whose views will greatly influence the ways in which our disciplines, and the economy, will progress in Scotland.

- We therefore recommend that a strong course strand should be introduced for all pupils to build "scientific literacy." (We call this *Science in Society* in this report).

4. The university community believe that science education at school should be designed to:

- build an appreciation of the historical and future significance of science and technology;
- build a basic understanding of the major ideas and principles of science;
- give an up-to-date view of selected areas of science, addressing some contemporary issues;
- engage interest and enthusiasm in pursuing STEM based careers, both academic and vocational and
- build scientifically useful skills in deploying knowledge and observation to explain and predict phenomena.

We would urge that these aims should be reflected at all stages in a new and coherent design of science provision for all age groups and streams of different ability and interests.

5. Overlaying all of our more subject specific conclusions are three major pleas, to encourage:

- strong focus on developing attitudes to education and work, in areas such as perseverance, self-driven initiative, and recognition of the longer term value of learning other than as a means to overcome a specific assessment hurdle;
- much more emphasis than at present on the key scientific skills areas of
  - numeracy and basic mathematical skills
  - 'literacy' developed in a scientific context
  - problem solving, particularly in more open and extended applications and
- an approach to the curriculum that is much less knowledge and assessment driven, accepting as a consequence a significant relaxation in the volume and comprehensiveness of assessment.

6. The content of school mathematics makes an important contribution to success in a wide range of Higher Education disciplines, including the physical sciences, engineering, computing and mathematics. Teachers in the biological sciences also stress the rapidly increasing importance of mathematics in underpinning their disciplines.

- University teachers believe that essentially all of the current content of H-grade Mathematics is important.
- Our participants, universally, would dearly wish future students to be more skilled in the techniques and applicability of mathematics and, in particular, they would wish to see improved skills in algebraic manipulation.

7. In all other school subjects considered the views of university academics are much more relaxed about redesign of current syllabus coverage, in order to accommodate more extended and "relevant" applications, and to foster broader skills development and reinforcement. Few specific topics are regarded as sacrosanct so long as an understanding of general underlying scientific principles and methodology is progressively developed.

    - Within the core sciences we would encourage giving much less emphasis to specific detailed knowledge. It is important to put this statement in context given that it is a key characteristic of science that great importance is attached to knowledge and evidence. Science is, however, about interpreting the implications of, and assessing the validity of, knowledge. It also identifies, and then pursues, what is unknown. Science develops central conceptual frameworks, and laws and models of behaviour, which allow us to organise and inter-relate knowledge, to make predictions about properties and behaviour, and to design new or improved devices or methodologies. Learning in science is not however fundamentally about committing large volumes of factual information to memory and proving later that this can be regurgitated. In relation to knowledge the priorities for school science curricula are:

- to instil a respect for valid factual knowledge as the cornerstone of all scientific analysis;
- to build a knowledge of central principles and models applicable in the subject area of study, and grow understanding of ways in which these can be applied and
- to achieve a general appreciation of the state of knowledge underlying chosen topics of study, and an ability to access, select and evaluate detailed relevant information as required.

8. In line with the aims suggested in item 4 above, we would wish to support a redesigned science curriculum that could provide a range of courses that would be meet the appropriate educational objectives whilst being exciting, relevant and also challenging to pupils at all levels.

    - Courses should have an inbuilt mechanism for rolling change to avoid growing obsolescence and a need for major review every ten to fifteen years.
    - We believe it is very important that the science curriculum engages the interest and enthusiasm of young people: we recommend that the international ROSE survey should be used in Scotland and should partially inform the design of new curricula.

9. We are concerned about the decreasing national uptake of Higher Technological Studies, and about the apparent low esteem in which this subject is sometimes held. We are concerned more generally that engineering has otherwise almost no profile in schools.

    - We feel that these issues should be considered in the context of the science curriculum review and we would be very keen to contribute to any processes aimed to improve the situation.

10. We believe there is a serious disconnect between the computing curriculum in schools and the discipline of computing science studied in higher education and applied in industry and business.

    - Here again we would welcome the opportunity to contribute to discussions aimed at addressing what we understand to be deep-seated and difficult issues underlying this very important problem.

11. Assessment structures and design will require to be substantially altered if the shift in emphasis proposed here for the school curriculum is to be realised. There will need to be a change away from the examination of mainly factual material to a type of assessment which will consolidate understanding and develop skills as well as measure achievement.

    - We would encourage changes made to this end and would be supportive of less comprehensive and less burdensome assessment.

- We would in general welcome arrangements liberating teachers to exercise much more individual initiative and professional judgement: we believe our recommendations as a whole encourage this and may indeed require it.
- In this context we would also welcome, where appropriate, significant weight being given to teacher-led assessment placing more trust and initiative in the hands of teachers through a "light touch" approach to moderation.
- We have reviewed statistical evidence from universities and find that the relative performance of students at degree level is only relatively weakly correlated with the strength of their school leaving qualifications: there is no need to regard the form of the current school assessment model as sacrosanct because of its reliability as a precise predictor for university admission judgements.

12. In order to better consolidate key capabilities, and to recognise the broader applicability of important principles and techniques, it is very important to encourage more interdisciplinary links and cross references between the sciences, other subjects and the world outside school.
    - Mathematical and numeracy skills can be reinforced by their timely application within science, literacy skills can be enhanced in expressing a scientific argument in extended writing, and skills in logical analysis can be exercised in studying science issues: in all cases science education can be enhanced whilst learning in another subject is reinforced.
    - The STEM disciplines should play distinctive roles in cross-curricular themes such as enterprise, creativity and citizenship.
    - It would be valuable to see more explicit cross referencing between science and technology subjects.
    - Science issues can provide fertile territory for cross-disciplinary exercises in interaction with subjects such as geography or modern studies.

<u>The way forward</u>

13. Since the publication of the *"Curriculum for Excellence"* Report, we have discovered that our views are shared by the Executive Committee of ASE Scotland. We share with them a keenness to contribute collaboratively to help ensure that the unparalleled opportunity offered by the Science Curriculum Review is successfully exploited. We have also met with a small representative group from professional bodies and industry and believe that they too would wish to join collaboratively in providing supporting and coherent input. This Review promises to be ground-breaking in the extent to which it may be driven by an overview of the needs of science education as a whole and for all. If the style of the curriculum is to change in the ways envisaged, it will involve topics which are beyond the career experience of currently practising teachers. We believe our university network, working in a collaborative and supportive role can:
    - provide access to an impressive range of expertise;
    - help assure the robustness of any new curricular structure adopted;
    - use our strong links with industry and institutions to marshal constructive input and
    - contribute collaboratively to the development and delivery of CPD for teachers.

INTRODUCTION

This year long project, running from mid February 2004 to mid February 2005, was funded by SEED to ascertain what Scottish Universities want from the school education of students progressing to study science, technology, engineering, and mathematics related (STEM) subjects at university. Preliminary results from this study were discussed with SEED officers linked to the progress of the first stage of the 3-18 Curriculum Review and it is hoped that this final report will help inform the thinking of the new Science Review group when it begins its deliberations.

The project was by design and direction restricted to questioning university lecturers and no currently active school teachers were consulted. There have been however interviews with members of university education departments and with university staff who have had recent school teaching experience.

Whilst universities must not attempt to decree what should constitute the curriculum in schools their views are very relevant as 50% of the school population progress to Higher Education. The views of industry should also be aired as approximately 25% of school leavers go directly to work and university entrants will in time enter the job market.

It is also important that the Science Curriculum Review Group appreciate the current opinions of the STEM community in universities, as there has been evidence in recent parliamentary debates, and anecdotally elsewhere, of perceived obstacles to change that university “requirements” might present with regard to alterations in assessment and the curriculum. It has in fact been found that the reverse is true and that universities would welcome quite radical changes in both areas if it produced net educational benefits and enhanced student interest in studying STEM subjects.

Initially our attention centred on the knowledge base that lecturers require of students. Matching exercises were carried out on each Higher subject and its university equivalent but as work progressed it became evident that general skills and attitudes are more important than a detailed knowledge of a large number of facts.

As it emerged that the main area of mismatch between schools and universities lies in the skills area, we were encouraged to delve back into the school curricula to see if reasons for this mismatch could be found and then to try to come up with ways in which improvements could be made. This involved a study of the 5-14 curriculum and Standard Grade courses in the appropriate subjects and the links between the three stages of curricula that cover the present school experience. The universities regard the planned integration of the school curriculum into one whole as being a major step forward.

Again, as work progressed, it became clear that we could not discuss the curriculum for those planning to progress to university STEM courses in isolation from that for the wider school population and we widened our remit to enquire what the experience of science in school should be for those not intent on science based careers. The knowledge and understanding developed by STEM disciplines has shaped the whole nature of our modern lives and will be the key driver for future change. It is important that *all* school pupils develop an understanding of the scientific principles involved and also that they are able to make informed decisions about scientific issues that are of concern today.

The Project and the Questions Addressed

The project was carried out in two Strands. Strand one involved two universities: the University of Glasgow and the University of Paisley. Three meetings of groups of lecturers were held initially to find out what the general impressions were and then individual interviews were held with 70 academics at the two institutions[1]. Lecturers came from faculties that cover the STEM subjects or require these as entrance qualifications. Lecturers were interviewed from the following subject areas: biology, chemistry, physics, geology, computing, engineering, mathematics, medicine, veterinary medicine, nursing and education. Prior to the interviews brief summaries of the appropriate Higher courses were produced and arrangement documents were made available on request. A questionnaire

[1] Names and subject affiliations for all academic participants are listed in Appendix A

had been produced but was used only as a check-list as we wanted lecturers to express their own views and not to be steered in any particular direction. Three questions were originally asked as a focus of our investigation:

1. What is most important in the school education of students progressing to study STEM subjects at university?
2. Are the school science, mathematics and technology subject curricula overloaded, inappropriately focused or out-of-date and do they provide the appropriate skills, attitudes and basic knowledge for progression?
3. How can concerns about the numbers of well-qualified school leavers applying for university places in STEM subjects be addressed?

As the study progressed it was concluded that it was inappropriate to consider the school education of those planning to pursue STEM subjects at university entirely in isolation. The circumstances in which the STEM community works, both in universities and across the wider economy, are strongly influenced by the general understanding of science amongst professionals, policy makers, and indeed the population as a whole, the great majority of whom are not science specialists. Further, the earlier stages of education cover common ground for all and it would not be beneficial to require irrevocable decisions to be made at too early an age as to whether to opt in or out of a route leading to later STEM specialisation. Accordingly a fourth question was added:

4. What broadly does the university STEM community believe is most important in the school education for those not in science-based careers?

After the initial interviews a group meeting was held to discuss the conclusions that were emerging. Every person interviewed was also emailed a copy of the conclusions drawn from the Strand 1 interviews and invited to comment on these. Several replies were received as a result of this consultation and a set of slightly revised conclusions drawn up.

Strand 2 involved meeting with groups of academics from the other eleven Scottish universities. These meetings were set up at the different universities and took a common form. There were 8-15 lecturers present at these meetings and a common agenda was used. We started by asking participants what they thought was most important in the school education of their students and only after this discussion did we show the conclusions we had drawn from the Strand 1 interviews.

We also gave a presentation at the Deans of Science and Engineering meeting and had discussions at a specially convened meeting of a group from the Scottish Science Advisory Committee at the Royal Society of Edinburgh.

In addition, four very helpful meetings were held during the course of the year with a widely representative Project Advisory Group who tried to keep us on the right lines[2].

Several students were also interviewed to get their impressions of how well their schools prepared them for university and several interesting comments were made (see section 2.iii. Literacy).

Preliminary matching exercises between Highers and the corresponding first year courses at the universities of Paisley and Glasgow were also carried out. These showed no major disconnects between courses at school and university, when compared on a subject basis, although lecturers did comment on where they might like a change in emphasis. The nine school subjects considered in this report are: Biology, Human Biology, Chemistry, Geology, Physics, Computing, Information Studies, and Technological Studies. [3]

[2] See Appendix B for the membership of the Project Advisory Group, and the organisations represented.
[3] Reviews of comments made by participants on individual Higher subjects are given in Appendix C.

CONCLUSIONS

What has been most striking in this project is the degree of unanimity achieved across the universities and the different disciplines. There is almost total agreement on all the conclusions reached.

What do university lecturers most want of their students?

This can be answered quite simply. They want:

- students with a curiosity and interest in the subject;
- students who know how to study independently and who are prepared to work and
- students with the skills and knowledge required to succeed in their chosen course.

What are the most common problems subject lecturers encounter with their students? Almost every lecturer mentioned the core skills of numeracy, basic mathematical techniques, literacy and problem solving before any comments were made about specific subject content. As the individual interviews progressed it also became increasingly evident that student attitudes are of prime importance. We had not initially envisaged discussing attitudes or 'learning culture' until we became aware just how widely concern about this area is shared. It emerged early on that the actual knowledge base required for entry to a particular course is of almost secondary importance if the appropriate attitudes and core skills are in place.

This 'wish list' of university lecturers can thus be sub-divided under three main headings:

1. Attitudes
2. General skills
3. Curriculum content

We will deal with these in turn.

1. Attitudes

As interviews progressed this emerged as the most significant factor for student progress.

Key attitudes identified by lecturers are:

- Motivation
- Persistence
- Initiative and keenness
- Ability to study independently

From the beginning of the interview process lecturers mentioned student attitudes, but not much attention was paid to this initially as we did not think that this could be addressed through the curriculum. However as we realised that attitudes were mentioned by almost every lecturer, and raised at every meeting at the Strand 2 universities, it was obvious that it was something that should be actively addressed. Many lecturers regard attitude as probably the key factor in student success. We also recognise that the curriculum and how it is delivered can influence attitudes, even though cultural and peer influences are also important, and felt that we should highlight these issues, hoping that addressing them could become an explicit aim of the Curriculum Review.

When graduate recruiters were surveyed[4] to find out the most important skills and attributes they look for in potential employees the most desirable characteristics are mainly personal attributes such as enthusiasm, motivation, initiative and commitment. The key skills are communications skills, team working, interpersonal skills and organisational skills. So attitudes are rated as important by industry as well as by universities.

[4] Keynote Project AGCA/AGR Subcommittee on Racial Equality.

Today we live in an "instant" society. Many students must now have everything immediately and have the most up-to-date mobile phone, clothes etc. To have these possessions, and to support themselves, they must work as well as attend university. Self-study time is not usually used for its intended purpose. As everything is "instant", the gaining of knowledge must also be instant and it is not appreciated that time must be spent assimilating and understanding material. In problem solving perseverance is essential.

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A fitness experiment[5] carried out by a PE teacher to compare today's pupils with those of twenty years ago measured how many times pupils could run between two points until they were too tired. The results showed that there were still some very fit pupils but that a large proportion of today's pupils did not achieve as well as their predecessors. The teacher could not decide if they were actually less fit or if they gave up sooner. He thought that some had given up before they were even out of breath. When he had discussed this with a mathematics teacher colleague, the colleague said that sometimes his pupils had their hands up for help with a problem before he had finished writing it on the board.

It is also much more difficult to impress pupils and students with simple laboratory experiments as their computer games show much more impressive sights. To compensate for this do we need to invest in ever more interactive and impressive demonstrations or do we need to alter the teaching approach to engage and involve the student more? There is a study, called the ROSE (Relevance of Science Education)[6] Project similar to the PISA[7] study which compares pupils from different parts of the world. It is a questionnaire that asks about interest in scientific subjects and interest and attitudes towards scientists and their impact on the environment. From the results of this questionnaire it is hoped that the different countries participating in the project can design a science curriculum suited to the needs of their pupils. The questionnaire is available to any country and it may be worth considering its use in Scottish schools to find what would motivate pupils to take science subjects. The results of the English survey are at present being analysed and so no information is available at present.

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Many students lack motivation and the ability to work on their own, whilst others are examination driven and want to know exactly what is required to get high marks in an exam. They study not so much out of interest but to pass the exam. This is probably not a new phenomenon but it seems to have become more marked over recent years and it may be a carry over from school where league tables published by the Press have encouraged an "exam culture".

The present schools system, with its over-emphasis on results of the end of year exam, does not encourage pupils to take responsibility for their own learning or motivate them to study. They suddenly move from a system where everything is set out for them to a place where they have to take more or less complete responsibility for their time management and own learning. Many students find this difficult. If pupils can be encouraged to take more responsibility for their own learning at school it may better prepare them for life at university and at work. It may be worthwhile considering alternative methods of teaching and of assessment for part of any course to encourage pupils to be more independent learners and to work both on their own and as part of a team.

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Two additional questions that must be asked are "Are pupils at school taught basic study skills?" and "Do the handouts and notes taken in schools facilitate study at home?" These questions may seem rather naïve but lecturers tell tales of pupils given booklets with spaces for additions to be made in class, a series of worksheets and problem pages all for the same subject. At the end of the day the pupils have a haphazard collection of notes with nothing in a logical order, thus making home study difficult.

Students are not all motivated to study and many do not seem to know how to go about it. Is it assumed at school that pupils instinctively know how to study for examinations? Many will, but for others knowledge of how to study may be helpful and it should not be left until the month or so before exams, but discussed throughout the school years. (This may in fact be done but several lecturers have mentioned this). Some feel that students direct their

[5] Article in a Scottish Daily Newspaper 2004.
[6] http://www.ils.uio.no/forskning/rose/
[7] "Learning for Tomorrow's World – First Results from PISA 2003" (OECD, 2004)

study very much towards a specific examination's structure, trying to identify "which fact or problem types" they may meet, rather than attempting to grasp the subject matter of the course as a whole and its themes and connections. Previous examination papers, and even better specimen answers if available, tend to be used as a primary rather than a secondary input to study. The more engaged pupils are in the learning process the more effective that learning will be and so perhaps different teaching methods should also be tried.

The importance of developing mature attitudes such as perseverance and initiative and approaches to education is regarded as crucial for student progress at university. This is regarded as a societal problem to some extent and so it may be difficult to make transforming improvement. It would seem key however to try to involve and enthuse pupils more in the learning process and to look at new ways of motivating disinterested pupils. The ROSE questionnaire could be used to find the science topics that pupils find interesting and this could be one of tools used when devising new school curricula. There is also the suggestion that a themed or applications led approach to curriculum design could also help. There is evidence from Scotland's project *Assessment is for Learning* that pupils become more involved with their studies if more formative assessment is used. This is discussed in more detail in the section on Assessment.

2. General Skills

Efforts have been made to improve general skills in schools for many years and this was one of the aims of the Howie Committee. In 1990 Professor John Howie of St Andrews University chaired a Committee set up to review the aims and purposes of courses and certification in the fifth and sixth years of secondary school education in Scotland. The Howie Committee reported in 1992[8] and identified nine main aims. The second of these aims was that "Schools should effectively develop core skills such as communication, numeracy, information technology, problem solving and working with others." In 1994, "Higher Still – Opportunity for all" was published by the Government[9], setting out its views on how reforms should be tackled in light of these aims. Higher Still courses were introduced into schools from 1999.

An evaluation of the Higher Still reforms was carried out by Roger Mullin[10] in Insight. The aim of his study was to evaluate the impact of the reforms from the perspective of key professional groups and stakeholders. As one of the key aims in the Howie Report was to develop core skills, this was investigated in the Mullin report. It emerged that the only core skills that had improved between 1999 and 2003 were IT skills. There was concern that communication skills seemed to have become weaker from 1999-2003. Numeracy and problem solving skills were not thought to have improved during this time either. The report goes on to say that:

> "schools share these concerns and can offer an explanation for this weakness. As there is a cross-curricular focus on these core skills, schools thought that this led to a lack of priority within individual subjects."

It was also felt that there was too much of a focus on assessment in school, rather than on teaching and learning: schools and others agree that the new National Qualifications can be used to develop core skills, but there is the need for further development of these skills if students are to be prepared adequately for the worlds of work or university.

From the results of this report it appeared that an improvement in core skills was needed in schools and this project wanted to see if indeed universities agreed with the conclusions of the Mullin report.

A very recent Scottish Executive National Statistical publication[11] however concludes that:

[8] The Howie Report available from HMSO, 71 Lothian Rd, Edinburgh, EH3 9AZ, ISBN 0 11 494204 8
[9] Higher Still – Opportunity for all, SOEID, 1994.
[10] Roger Mullin Insight-An Evaluation of the Higher Still Reforms, December 2003, Scottish Executive Education Department. http://www.scotland.gov.uk/insight/
[11] 5-14 Attainment in Publicly Funded Schools (2003-2004)

> "it is encouraging that the percentage of pupils reaching key levels in numeracy has increased at all levels since 2001. At S2 the percentage of pupils reaching the attainment Level E in Mathematics has increased by 8.3% since 2001 and is now 59.5%."

Hopefully this improvement will filter up through the S3 to the S5 and S6 years in due course.

The six general skills regarded by our project participants as of particular importance are:

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- Numeracy
- Mathematical ability
- Literacy
- Problem solving skills
- Practical skills
- IT skills

2.i. Numeracy

There are wide concerns about the problems students have with ratio, proportion and fractions. Competence in these basic numeracy skills is vital in science and engineering subjects. It is thought that some of the problems encountered in numeracy and mathematics could be attributed to a lack of understanding of fractions at primary school. Basic algebra becomes much simpler if the pupil is able to handle fractions with confidence.

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Chemistry students tend not to perform well in calculation questions in examinations. The Principal Assessor stated in the report for the 2003 Higher Chemistry examination that students should "*learn the basic routine for the different types of chemical calculations*" as generally these were not well done. The examples stated involved percentage yields, excess in mole calculations and an equilibrium calculation. In contrast, in the Physics Higher paper calculations are much more numerous and appear to be reasonably well done (45 out of the 70 marks in Section B are given for calculations). This may be because students who are good at mathematics are encouraged to take Higher Physics, or it may be that the two subjects reinforce one another i.e. more practice in problems in physics helps performance in mathematics and vice versa. Our university colleagues commented that they feel that physics students are quite competent in "arithmetic" handling problems: coping with "algebra" is however a different story.

In the report on Higher Mathematics for 2003 there was a comment that arithmetical errors seemed to be on the increase. At university chemists and biologists who teach material requiring calculations raise concerns about general numeracy. The mathematical nature of chemistry at school seems to have been played down in recent years and as a result pupils are not getting as much practice in calculations as they perhaps require. Many university lecturers are deeply concerned that entrants arrive with strong expectations that the study of biological subjects will not require significant use of numeracy or mathematical skills; in reality the biological sciences are becoming increasingly mathematical in nature and so proficiency is required in both numeracy and mathematics.

Engineers do not all encounter students with numeracy problems but several consider that fractions, long division and multiplication are problem areas. One lecturer commented that arithmetic has improved recently and this may be due to the introduction of a paper in the Higher Mathematics where the use of calculators is not allowed.

Students in all disciplines are particularly poor at estimation and seem to lack recognition of the significance of scale. Most do not estimate or check an answer and have no critical sense as to whether an answer is reasonable or not. This practice is something that needs to be reinforced. There are numerous examples quoted of students believing blindly in their calculator. Feedback on the Standard Grade Physics from the Principal Assessor in 2004 said that pupils did not check to see if an answer was reasonable. In a question on how much of a saving a farmer could make if he used a wind-powered generator for 8 hours, answers ranged from 0.8p to £540 000 000, when the correct answer was £14.40! On a not too dissimilar note he also commented that unit conversions are not well done and that many pupils think that MA and mA are the same thing. An example from university is the calculation of the volume of one component of a cell (a lysosome) where the answer of 14 litres was given with confidence by one student.

How can the situation be improved?

In Standard Grade and Higher Mathematics there is now one paper in the examination where the use of calculators is prohibited and this appears to have had a positive effect. If the standard of numeracy is to improve there needs to be reinforcement of the basic skills throughout the school curriculum. A Report for Consultation- Updating Chemistry Courses, May 2004 was circulated by SQA which proposes that numeracy skills should not be taken for granted but are developed and applied as part of the courses from Access through to Higher. In Higher it is suggested that skills in scientific notation and understanding and interpreting graphs should be developed. There are many areas in the current syllabus which provide opportunities to give more emphasis to improving numeracy, as could the introduction of more open-ended applications. Indeed, reinforcement of numeracy skills should be possible in all the science subjects.

Initially our study focussed almost entirely on subjects at Higher level, but on considering numeracy we began to look at the earlier years in school and the connections between the 5-14 Curriculum[12] and Standard Grade and also between primary and secondary education. Work with fractions in the 5-14 curriculum is very restricted and is not expanded until Level F where the pupil is asked to: convert fractions to decimals; add, subtract, multiply and divide fractions; split a quantity in a given ratio and use direct and inverse proportion. Only a small proportion of pupils are expected to achieve Level F by the end of S2.

The majority of pupils will have completed Level E by the end of S2 when they will now be ready to start Standard Grade in S3. Addition, subtraction, multiplication and division of fractions are introduced in the 'Number' section in Standard Grade It should be noticed that the four operators are applied to fractions only at the Credit level. Direct and inverse proportion is also covered in Standard Grade and algebra is introduced in the section on 'Relationships'.

If schools follow the 5-14 guidelines and most pupils only achieve Level E by the end of S2 it would appear that there is very little work done on ratio, proportion and the handling of fractions in primary school and indeed there may be very little in the first two years of secondary school either. This means that pupils have not had any time to familiarise themselves with these concepts before they tackle algebra in the same year. It appears that a knowledge of fractions was not thought important, at some stage, due to the increased use of calculators and decimalisation but this has had a deleterious effect on the ability to manipulate mathematical equations and on the ability to calculate both direct and inverse proportions.

Skill in the basic manipulation of fractions underpins the concepts of algebra, so if pupils do not have enough exposure to this then they will ultimately struggle with further mathematics. It is recommended that there should be more work carried out in primary schools on fractions and also on ratio and proportion so that pupils become more familiar with the handling of fractions at an earlier stage so that they will be better prepared to tackle algebra in secondary school. It has been suggested that some primary school teachers may be uncomfortable with teaching fractions and that professional development would be useful.

[12] See Appendix D for the 5-14 mathematics levels

To summarise:

- Numeracy skills, including handling fractions, ratios, proportion and percentages, need to be improved.
- It is suggested that perhaps more effort is put in to improving these skills at the primary school stage and that these numeracy skills are reinforced across a range of subjects within secondary schools.
- The ability to estimate and assess the reasonableness of an answer needs to be developed.
- An appreciation of the relevance and significance of scale is important and requires reinforcement.
- Numeracy should be reinforced throughout the STEM subjects at school.

2.ii. Mathematical Ability

Most lecturers are concerned about the basic mathematical ability of students. Even well qualified students appear to lack competence in basic algebraic manipulation and this is crucial, not only in the rest of mathematics itself, but also in solving mathematical problems in the sciences and engineering.

One lecturer at the University of Glasgow had collected comments, dating back to 1984, from Principal Examiners reports in mathematics examinations. These are listed below:

"It was very disappointing, however, to find that many candidates experienced difficulties attributable to poor, and in many cases careless, manipulation. C.S.Y.S. 1984."

"A considerable drop in the standard of algebra was noted. Standard Grade Credit 1993."

"It was disappointing to see frequent mishandling of vector work and algebraic errors. Higher 1993."

"While the overall marks were satisfactory, it was disappointing to see many casual errors, poor algebraic manipulation…. Higher 1994."

"The attempts at question 15, algebraic techniques leading to integration by partial fractions, were poor. Algebraic errors were widespread. C.S.Y.S. 1996."

The inability to manipulate equations has obviously been around for at least twenty years.

Mathematics, as well as being an intellectual discipline in its own right, also provides the underpinning language for science, engineering and other disciplines. One lecturer comments that we are selling our young people short if we do not equip them with the basic mathematical ability to cope with science and engineering subjects.

It does not seem that enough time is allocated at school to give as much practice as is required for mastery of the required skills. More practice should be given using examples of gradually increasing complexity. Basic algebraic skills can also be reinforced in other subjects.

At the Robert Gordon University, in Aberdeen, diagnostic numeracy/ mathematics tests[13] are given at student entry so that problem areas can be identified and remedied in the first few weeks of term. This has been introduced because lecturers can no longer rely on students having the basic skills in numeracy and mathematics, and Appendix E illustrates just how fundamental these difficulties are.

At Strathclyde University there is a 'Foundations' course, that everyone who requires to study mathematics as part of their degree course must take. Again this has been introduced to make sure that everyone has a reasonable fluency in the different mathematical techniques, as it does not seem that a pass in Higher Mathematics now guarantees this in all students. The introduction to the Foundations booklet states that "*Mathematics is a subject*

[13] For examples of questions and the responses to them see Appendix E.

that continually builds upon itself. Further progress in mathematics depends upon all that you have learned through primary school and secondary school. Many mathematical skills and concepts that were introduced in primary school or early secondary school become "common sense", indeed that is what they are! But some mathematics that you have done more recently may not have "sunk in " yet to the extent that you are completely confident about applying it as and when required." The course goes on to revise a good deal of basic mathematics, particularly algebra.

Further on in the booklet it states that "mathematical skills are learned by practising them – mathematics is a participative sport!" It also points out that success in mathematics is based upon understanding and doing.

Another area of mathematics where there is concern is in the understanding and handling of logarithms, exponentials and the laws of indices. The laws of indices are handled at Standard Grade and appear to have been forgotten by the time university is reached. Logarithms and exponentials form part of the third Mathematics unit at Higher and there is the impression that this is sometimes rather rushed and students do not have time to assimilate the ideas introduced. Most lecturers want students to have a familiarity with logarithms and exponentials, especially those studying the physical sciences and engineering. The significance of the pH scale in chemistry cannot be appreciated if the student does not know about logarithms. Similarly the concept of half-life in radioactive decay cannot be understood without a knowledge of exponential functions. It is suggested that these mathematical concepts could be illustrated in the sciences and so help with student understanding. We believe there is scope for some groundwork to be done within the sciences on introducing these concepts from a rather earlier stage.

More detail of the comments on the current Higher Mathematics curriculum is given under the subject specific heading in Appendix C.

To summarise:

- Competence in basic algebraic manipulation is the main area where improvement is required, as lack of it prevents the development of other skills.
- Students' understanding of the laws of indices, logarithms and exponentials needs to be improved. It is suggested that these concepts can be referred to in other subjects, e.g. pH in chemistry and radioactive decay in physics.
- Basic algebra should be further strengthened wherever possible in the school curriculum.

2.iii. Literacy

Two specific problems are identified: the first is the use of grammar and punctuation and the second, which interferes fundamentally with communication, and perhaps personal understanding, is an inability to produce coherent extended writing. The ability to develop arguments and produce a structured essay seems to have declined. This difficulty in producing a piece of extended writing was highlighted by biologists, chemists, veterinarians and some physicists and engineers. It is also apparent in the poor quality of laboratory reports for subjects where these are required. Most lecturers regard students' reading and information gathering skills as good, the problems arise once the information has been gathered. Students seem to have difficulty presenting the material in a structured and logical fashion.

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Across the Higher sciences only the Biology and Geology examinations have any essay type questions. In both subjects twenty marks are allocated to essay questions. The Biology Principal Assessor's report for 2003 states: *"The generally poor candidate performance in the extended response questions is mainly due to an inability to a) state factual material clearly and simply and b) organise the information into a logical sequence"*. We found these comments echoed by lecturers across many disciplines at university. There are two essay questions for ten marks each in the Higher Biology paper and generally at least one of the questions is broken down into several headings.

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In Higher Geology essay writing was described as an area of weakness. In physics the Principal Assessor commented in 2002 and 2003 that students needed more practice in questions "*involving description and explanation*".

In the Higher Chemistry paper most of the questions are for single marks and a maximum of two marks is allocated for an explanation, requiring two distinguishable elements, so there is no requirement for extended writing.

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Universities have noticed a decline in the essay writing ability of students in recent years and have therefore altered examination question papers in the first two years of some courses in such a way that they consist almost entirely of multiple choice and short answer questions. This has led to the problem being displaced further up the educational ladder and Learning Advisers at the University of Glasgow say that students come to them in 3^{rd} and 4^{th} year wanting help with essay type questions in addition to help in writing up 4^{th} year projects. So universities in turn are having to recognise that if these issues are not faced early they become ever more critical because these skills are vital for research and for graduates more generally.

There have been comments from several universities on the precise use of language. In the sciences and in engineering it is important that information is transmitted in a clear and non-ambiguous manner. The precise use of language is imperative in instruction manuals, contract documents and in conveying scientific information. An example of this given at Napier University is that any software developments must be accurately documented otherwise the software would be useless. At this university, in their Professional Computing degree courses, they find that a useful predictor of how well a student will perform on the course is the possession of good essay writing skills.

Several of the students interviewed said that they were in agreement with the conclusions drawn regarding literacy. They commented on the lack of any teaching of grammar in schools and made a plea to have grammar formally taught in primary or early secondary school!

The report from the Assessment of Achievement Programme[14] commented on the relatively poor writing skills at all stages from 5-14. Fewer than 10% of the P7 and S2 pupils produced writing that was rated as being at the target levels for these stages (Levels D and E respectively).

To summarise:

- Students need more practice in articulating ideas in extended writing.
- Grammar, spelling and the correct use of language need to be improved so that communications are clear and accurate.
- The introduction of a project in a science subject could help improve literacy skills.

2.iv. Problem Solving Skills

The three science courses (Biology, Chemistry and Physics) at Higher each consist of three units. Each unit has three outcomes of which the second is on problem solving. An example of this outcome in the Cell Biology unit in Higher Biology can be seen in Appendix F. Lecturers are impressed with this document but doubt whether its aims are achieved, particularly in the ability of pupils to actually plan, carry out and evaluate experimental procedures. The ability to problem solve more generally is thought to be poorly developed by lecturers in many subjects, though some lecturers in the medical faculty have been impressed by their entrants' success when thrown into a problem-based learning regime.

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In mathematics the outcomes are written differently and the problem-solving element is discussed in the Grade Description part of the document[15]. The information on problem

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[14] AAP Assessment of Achievement Programme – the Sixth Survey of Science 2003 produced by the Scottish Executive.
[15] See Appendix G for Grade descriptions.

solving in the Science Outcomes seems mainly to apply to experimental work, collecting information from graphs, solving numerical problems and solving problems on specific topics. In mathematics it is about interpreting the problem, selecting an appropriate strategy and implementing the strategy. In general the outcomes sound quite impressive but it appears that pupils can "learn" how to solve a particular problem in one situation but cannot apply the technique readily in another area or they may not be able to modify a particular strategy to a different situation. Students find it difficult to solve the more extended problems where strategies may need to be modified and used in combination and the universities would like to more problems of this type undertaken.

We know what the arrangements documents tell us about problem solving, so how does this match with university expectations and experience?

What do lecturers mean by problem solving?

A common answer is that students cannot apply principles in a new context. They are also poor at analysing the nature of the problem and there seems to be a lack of enforcement of concepts and lack of practice. If a mathematical problem is set in a science subject students have difficulty in substituting into the correct equation and may not know what equation to use. Cases are also cited where pupils have been given three equations to remember for Ohm's law! This is presumably one teacher's way of getting over the problem pupils have with the manipulation of equations.

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In mathematics, problems involving basic algebra cause difficulties. At school pupils solve equations involving x, y and z but if, for instance, p, q and r are used instead this causes confusion. Students can solve the equation $ax^2+bx+c = 0$ but may not be able to solve $ax^2+bx = c$. Lecturers think that more practice with graded questions, using different symbols, and then problems involving practical examples would be helpful. This is material that is covered at Standard Grade and so it is perhaps not tested at Higher. Algebraic manipulation is a vital mathematical technique as it is used routinely in other areas of mathematics and also in the sciences. Mathematics is a subject that continually builds upon itself and so if the basic techniques are not acquired it is impossible to progress.

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At school pupils seem to be coached on how to tackle specific problems that come up in their exams and even the so-called problem solving questions become in reality only exercises in recall. What is wanted is for the students to be able to develop actual problem solving skills during the course rather than them being coached to pass an exam. We realise that this is perhaps a strongly put critical comment, and that to address the issue will be far from simple and, if done without great care, may simply make courses more difficult for pupils. We feel the answer must be to recognise this as an agenda from an early stage, and to work strategically across subjects in the curriculum so that skills are gradually enhanced stage by stage and in a way in which pupils across the ability range can steadily progress. The importance of open problem solving skills in all areas of life is huge, whether based on numeracy, logical analysis or imagination. The evidence from the medical faculty suggests that if a person is interested and engaged in a problem that is relevant and interesting to them they will persevere in efforts to find a solution to the problem posed.

Students seem to think that problem solving should come instantly and easily. They do not realise that it takes time and that they have to persevere with a problem, looking at many ways of tackling it before they succeed. Sometimes a problem must be broken down into its component parts and each part solved separately and again many students are very poor at this. Students tend not to be experienced in pattern recognition and do not see the links between different pieces of information. Often students cannot make the first step in a problem as they cannot see it in overview, so it is not known if they would be good at solving the rest of a problem as they do not get past the first hurdle.

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Students often find it difficult to distinguish between cause and effect. They also have difficulty with comprehending the nature of a problem, as they do not always understand the language in which the problem is written. Students do not always answer the question that is asked and often give a description of a phenomenon when an explanation should have been given. These phenomena are probably not really to due to poor problem solving skills as such but to the communication skills of the student and the inability to interpret what is required from the question asked. It is important that students can not only use language in a precise fashion but also be able to interpret correctly what is written. We feel it is important to recognise that there are links between some problem solving and literacy skills.

Is there a solution to this?

For mathematical problems an important component of the answer seems to be more practice and the introduction of a range of problems starting with the simple and progressing to the more complex. For non-mathematical problems however the prescription is not so simple. Before a problem can be solved in a science subject the student needs to be familiar with the topic being studied. There also appears to be a problem with attitude here: if the answer does not come immediately then the student gives up. Does this imply that the student is not particularly interested in the topic and, if so, how can his or her interest be better engaged?

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It would also be useful, throughout the years of secondary school, to build experience in tackling more extended and open-ended problems in science subjects. These exercises may involve information gathering and presenting as well as practical exercises. There is evidence[16] that learning is improved when students are allowed to work in pairs or in small groups. When people discuss with others the problems they are experiencing with understanding a particular principle or problem this seems to help the learning process and also to help everyone in the group. And when success is found to follow perseverance, it can be hoped that confidence may grow: it can be comforting to learn for oneself that genius is 99% perspiration and 1% inspiration!

At Glasgow University the medical faculty use a problem based learning (PBL) approach to the whole medical course and this involves students working in groups with the aid of a facilitator. This seems to greatly aid the learning process and it has been noted that if, in third year, these students take options which are in fact delivered and examined in the traditional way, the students perform noticeably better now than students in the past who had experienced a lecture oriented course. It had been expected that the PBL students could have been at a disadvantage as they were not used to lectures and note taking, but the opposite was found to be true.

To summarise:

- For mathematical problems, more practice with problems of gradually increasing complexity could improve the situation.
- Problem-solving in non-mathematical situations could be improved with the introduction of more open-ended and extended problem-solving exercises. Some of these could be carried out on an individual basis and others in small groups.

2.v. Practical Skills

It is very noticeable that when looking at chemistry courses in particular, from different parts of the world, there is much less emphasis on practical work within the Scottish Higher syllabus. Most lecturers favour the introduction of more practical work in school courses. They would like pupils to carry out more practical work on their own and to be involved with more extended and relevant experimental work. This would not only develop practical skills in the student but would hopefully stimulate their interest in the subject and aid the understanding of principles. As mentioned earlier it would also enhance problem-solving skills. Practical work in schools appears to have declined over the years due to Health and Safety and financial considerations. If the content of current syllabuses was reduced it would hopefully allow more time for practical work. Pupils should be introduced to and understand the need for risk assessment. Whilst chemistry is the subject where we had most comments about the need to enhance practical experience, this is an issue of interest across all of the sciences.

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The opinion of the effect of externally assessing practical work in school is that it actually has the effect of reducing the amount of practical work done and it does not seem to

[16] Assessment is for Learning project http://www.ltscotland.org.uk/assess/about/evaluation/index.asp

improve the report writing ability of the pupil. Many lecturers think that experimental work as such should not be externally assessed. We have the impression that external moderation has distorted the object of the practical exercise to be focused on producing a defined pro-forma report as evidence, rather than on encouraging more open-ended learning from the practicals themselves.

To summarise:

Practical work should be designed to:

- build skills in manipulation, observation and analysis;
- aid understanding of science principles covered in the course;
- communicate the sense of excitement, which pervades the sciences and
- provide one route of connection between science teaching and the 'real world'.

2.vi. IT Skills

Basic IT is the one area where skills are universally recognised to have improved in recent years. Most students are computer literate and can use a word processing package, databases and spreadsheets and can access the internet for information.

Where the universities are not so happy is the suitability of the Higher in Computing as a preparation for computing science courses at university. A revised Higher is being introduced this session (2004-2005) and according to lecturers they are unclear how much programming it contains, and consequently how much more appropriate it will be, as a grasp of the basics here are needed for easy progress in computer science courses. At present admissions officers think that the possession of a good pass in Higher Mathematics is a better indication of suitability to cope with a computing science course. This is discussed in detail in the section on Higher Computing.

2.vii. Summary of General Skills

The key general skills are regarded as important as specific subject content. It is suggested that numeracy and literacy, in particular, need to be continuously enhanced starting within primary schools and that all the core skills should be strategically and coherently reinforced at secondary school across the curriculum, with a strong input from within the science subjects. The inability to manipulate equations by even the most able students is identified by very many lecturers as a particularly serious matter of concern. Any new curriculum should also place emphasis on more extended problem solving exercises.

3. Comments on Current Curriculum Content.

To study the knowledge base required for entry to specific courses, lecturers interviewed during strand 1 of our work were given summaries of the appropriate Higher arrangement documents and the actual documents were taken along to the interviews.

We originally looked at nine Highers and were encouraged to have a brief look at a further two. The Highers in question were: Biology, Chemistry, Computing, Geology, Human Biology, Information Studies, Mathematics, Technological Studies and Physics followed by Product Design and Graphic Communication.

3.i. Science Subjects (Biology, Chemistry And Physics)

Many of the remarks made by lecturers are similar for the three sciences[17] and so are presented together. Two geology lecturers were interviewed but as Higher Geology is not a required entry qualification for entry to geology, and only about 50 pupils take it per year, no detailed study was done on this subject. The two lecturers interviewed are happy with the content of the Higher but comment on the lack of general skills and on the lack of an appreciation of scale in their students.

There had been comments in various reports[18] that the science subjects are overloaded especially when the Higher is taught in a "two –term dash". Concerns have however also been expressed that the topics covered are all required for university entrance.

There is general agreement with the first statement above and lecturers, in general, consider that the amount of material that has to be covered in a short time for the Higher sciences leads to very superficial learning and they welcome the idea of freeing up time in school courses. The universities realise that their subject areas have become vast and they try to give an insight by studying a few areas in depth so that the student can gain the skills and techniques of science combined with a knowledge of the fundamental underlying principles. They would have no real objection to schools following this example. Universities are looking for enquiring minds and a knowledge of the basic principles. So universities will now take a more relaxed view on topic coverage and want instead more emphasis on basic principles, more extended problem-solving activities and more relevant practical work. It is hoped that a new science curriculum can be designed in such a way as to enthuse, motivate and interest the pupil.

It has been reported that pupils in early primary school are keen on science but as they progress through school their interest declines. This may be partly due to the poor link up between P7 and S1 in the 5-14 curriculum and also to the apparent non-relevance to pupils of Standard Grade and Higher topics (Standard Grade Physics is possibly an exception to this). There should also be time in the syllabus to study a topical or controversial issue in some depth so that pupils can see how informed decisions can be made by weighing up the available evidence. This is also an area which interests pupils and so it may help foster interest in the sciences. There is also a plea to free up time in the curriculum so that teachers can demonstrate the wonder of the subject. Most see areas of the existing curricula where cuts could be made and this is discussed in more detail in Appendix C. Chemistry, in particular, is seen as overcrowded with a huge number of disparate facts to be learned.

Universities are very aware that there have been many changes to the school curriculum, in recent years, and hope that any new curriculum will be capable of rolling change so that it can be kept up-to-date and will avert the need for major changes in the future.

The numbers entering university have increased greatly in the last 20 years and now approximately 50% of the school population progress to FE or HE. This in turn has caused universities to modify their first year programmes and to offer more in the way of remedial classes and tutorial back up. We have made it clear above that key skills and attributes that were perhaps implicit in older approaches to teaching and assessment now need to be actively and explicitly engaged. This is shown by inadequacies in study skills, the inability to think clearly and logically in addressing multi-step problems and constructing well-structured essays. To better prepare pupils for university life, and science courses in particular, it is thought necessary to develop skills and attributes throughout the school subjects. Science subjects offer an ideal platform to develop numerical, mathematical, literacy and problem solving skills as well as analytical skills. And in addition, science should surely be making its contribution to agendas in enterprise, citizenship and creativity.

The apparent lack of real practical work within schools is a matter of concern to many lecturers, who regard it as an ideal vehicle to help understanding of the theory, develop required critical and analytical skills and generate an enthusiasm for the subject. The

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[17] See Appendix C for a more complete summary of the three sciences.
[18] Why Science Education Matters: Supporting and Improving Science Education in Scottish Schools, November 2003 The Scottish Science Advisory Committee.

present courses and examination system seem to produce students who only “half know” a huge number of facts and who lack practical abilities or knowledge of how to carry out a scientific investigation. When comparing chemistry and biology courses, in particular, with those from other countries there appears to be much less emphasis on practical work in the Scottish Higher courses.

As the courses are seen as overcrowded for the time allocated this, for many, leads to a lack of understanding of the significance of explanatory principles relative to factual minutiae. There has also been an increase in the number of assessments a student takes throughout the year and this seems to further encourage an “assessment drive” at the expense of subject interest. There is broad agreement across the universities that there needs to be a change of emphasis in school courses towards more understanding of basic principles and to encourage this by means of more relevant practical work. There could also be more extended practical work to help develop investigative skills and problem solving abilities. Within the sciences there should also be some space to discuss recent contemporary issues so that students can learn how to make informed decisions on these issues. It has been hoped that the concept of “risk” could be incorporated within this. It is appreciated that all these requirements need substantial space to be made in the curriculum, particularly if the “two term dash” for the Higher is to continue. On being asked if there are places where content could be removed from the courses, the answer from those consulted is generally a positive one. Development of an understanding of principles, an enthusiasm for the subject and possession of the general skills are all regarded as more important than any individual specific topics in the present prescribed syllabi. Research in science subjects at university increasingly spans the borders of the different sciences and so researchers need people with an appreciation of the three sciences. Also in schools there are decreasing numbers taking two, let alone three sciences. The suggestion has been made on several occasions that a combined Higher Science (consisting of chemistry, biology and physics) might usefully be offered at a double credit rating.

The 5-14 Curriculum – Environmental Studies: links between primary and secondary school and between the 5-14 curriculum and Standard Grade.

The Science component

There are three areas within the science component of the 5-14 curriculum:

- Earth and Space
- Energy and Forces
- Living Things and the processes of life

A copy of the syllabus through the six different levels A to F for each strand appears in Appendix H.

There are six levels within the different strands from level A through to Level F. It appears that Level F is there to challenge the most able pupils and it is not envisaged that all will even start this level. It also appears that not all pupils will complete Level E as some schools change over to SG towards the end of S2. This makes it very difficult to know on what foundation Standard Grade should be built as different schools and different pupils could have different starting points. The order in which the science subjects are taught in S2 is also variable depending on whether it is taught as a single subject or broken up into chemistry, physics and biology. This can cause a problem when it comes to making choices in S2. The choice of which sciences to take may be made before one of the subjects has been taught. Another remark made is that if the environmental science is taught as an integrated whole pupils may not be aware of what parts can be classified as biology, chemistry or physics and this can make subject choice of Standard Grade more difficult.

Pupils in primary school appear to love science and in a number of local authority areas a lot of good work has gone in to providing teaching strategies, teaching material and professional development for primary school teachers to help them with the 5-14 science curriculum. As the syllabus is not broken down year by year, and pupils may work at their own pace, good records need to be kept and then transferred to the next class. This is probably quite easy to do within a primary school but becomes more difficult at the P7 to S1 transition. Several primary schools feed into the one secondary school and while there are liaison activities between most schools it must be very difficult to give a smooth transition for all pupils. It appears that some secondary schools repeat experiments and factual material that has already been covered in primary and this may have the effect of turning pupils off science. There is the impression that in some schools pupils are not now so well prepared for Standard Grades in science subjects as previously, before the implementation of the 5-14 Curriculum. While the idea of the 5-14 Curriculum is lauded, in that it should give a good progression between primary and secondary school, in practice, because not all the material has been taught in the six levels, it has left the transitions from P7-S1 unsatisfactory and from S2-S3 more problematic.

If what was to be covered by the end of P7 in the Environmental Science part of the 5-14 curriculum was defined this might make the transition between primary schools and the secondary school easier. The link between what is taught in S1 and S2 and the Standard Grade could then be explored. It could be decided what in Levels E and F is required for progression and if further material should be added or removed.

The AAP report on Science 2003, quoted earlier, states that:

“fewer than 10% of P7 and S2 pupils were secure at the target levels for the appropriate stages, i.e. Level D for P7 and Level E for S2 and indeed the majority (75-85%) failed to show evidence of basic attainment at these levels (fewer than half marks scored). Just over a third of P7 pupils were classified as secure at Level C and just under a fifth were similarly classified at Level D. No S2 pupils were secure at Level F.”

In the document Improving Science Education 5-14[19] it was recommended that with the information provided from the primary schools it should be possible to place pupils in attainment groups and this would prevent pupils having to repeat work they had already done. The use of worksheets and workcards is not recommended either as it causes pupils to spend too much time copying out material and even “cutting out and colouring in”. It has been found that countries which do well in the TIMSS[20] study are those who are involved with direct teaching of pupils. This involves giving clear expositions and explanations and interacting with pupils through questioning and discussion. The report recommends that teachers should spend most of their time working in this way with pupils either as a whole class, group or individuals.

The report also recommends the setting of clear targets for learning, supported by associated assessment schemes. This enables teachers to focus their teaching and so raise standards.

3.ii. Summary of Comments on Science Curricula

Our university participants agree that:

- The current science syllabi are overloaded for the time given.
- They now have a more relaxed attitude to topic coverage.
- There should be more emphasis on basic scientific principles.
- A few topics should be covered in depth.
- There should be more extended and relevant practical work.
- Any new syllabus should be designed to enthuse and be relevant to the student.
- Core skills should be embedded within the curriculum and should involve more extended problem-solving activity.

[19] Improving Science Education 5-14, Scottish Executive Publications on http://www.scotland.gov.uk/library2/doc09/imse-02.asp
[20] TIMSS Report available at http://timss.bc.edu/timss2003.html

- A contemporary or controversial issue should be incorporated to help pupils make informed decisions. Hopefully this could encompass addressing understanding of the concept of "risk".
- The links between the 5-14 curriculum, Standard Grade and the Higher should be improved to give a better progression.
- For the above changes to occur there must be a significant change in the method of assessment. Universities are happy that this should take place.

The proposed changes are illustrated in section 3.iv.

3.iii. Knowledge Within Science Education

Much of the thrust of our conclusions implicitly advocates change to give less emphasis to detailed knowledge. Yet attaching great importance to knowledge and evidence is a key characteristic of science!

Science is fundamentally about interpreting the implications of, and assessing the validity of, knowledge. It also identifies, and then pursues, what is unknown. Science develops central conceptual frameworks, and laws and models of behaviour, which allow us to organise and inter-relate knowledge, to make predictions about properties and behaviour, and to design new or improved devices or methodologies. Learning in science is not, however, fundamentally about committing large volumes of factual information to memory and proving later that this can be regurgitated. In relation to knowledge the priorities for school science curricula are:

- to instil a respect for valid factual knowledge as the cornerstone of all scientific analysis;
- to build a knowledge of central principles and models applicable in the subject area of study, and grow understanding of ways in which these can be applied and
- to achieve a general appreciation of the state of knowledge underlying chosen topics of study, and an ability to access, select and evaluate detailed relevant information as required.

Making science education more interesting and relevant may also be dependent on giving much less emphasis to requiring retention and recall of highly specified detailed topics.

Students achieve best when they are engaged, when their interest is aroused and when they can exercise a degree of personal initiative. They can feel a sense of accomplishment through having understood some concept more thoroughly and appreciated the power and significance of an idea or theory or solved a meaningful problem. Universities will benefit if entrants have a strong commitment and interest in their selected area of study based on an appreciation of its importance to our life and world. Good teachers can make all the more impact where the relevance and inherent interest of the curriculum topic is most obviously clear.

School courses must of necessity give attention to foundation building, developing tools and a knowledge base upon which a thorough understanding of the pinnacles of science can later be built. This should not be an exclusive focus, however as it is important at all levels to keep the power and present-day relevance of the subject in ready view. It is also of great value in developing science skills that some issues of current controversy are reviewed, to demonstrate how a scientific analysis can deepen the level of any debate, and is in fact essential to achieving a rational policy outcome. There is also clear evidence that school pupils wish that their science education took this approach[21].

[21] How do we interest pupils in `boring' science? A: Teach them ethics, history and philosophy. The Independent (London, England); 1/16/2004; Cassidy, Sarah and http://www.ase.org.uk/htm/journals/eis/pdf/pdfeisfeb.p4.pdf and http://www.kcl.ac.uk/depsta/education/publications/Pupils_Report.pdf

3.iv. The Way Forward: What A New School Science Curriculum Should Aim To Achieve.

Table 1

Perceived issue in the present system	Recommended response
Fact filled static curriculum	"Free up" the curriculum, declutter to concentrate on core principles, study a few topics in depth, introduce science for all and discuss controversial issues. Above all involve the pupil. Investigate the introduction of more themed or application led curricula to interest and motivate the learner. Place more emphasis on developing core skills. Consider the balance between integrated and single disciplinary curricula in the sciences.
Assessment driven culture	Reduce assessment and make assessment fit for purpose. Relate assessment to teaching. Place more emphasis on overall achievement across all subjects studied as a measure of general educational achievement. Look at results of research
Externally marked experiment plus other short experiments	Stop external moderation of practical. Introduce more and extended practical work, particularly in chemistry and biology.
Compartmentalised knowledge	Form links with other subjects in the school curriculum (this would improve core skills)and between each science subject and real life including careers. Development of an integrated project should be considered. Show the contribution that science can make to enterprise, creativity and citizenship.
Pupil not active in learning – he/ she is to an extent force fed, tutored to pass exams, not encouraged to think and inform opinions, possibly does not relate to subject.	Pupil should be encouraged to learn and study independently and also to work in teams, and be encouraged to form opinions. More extended and relevant practical work should be undertaken. Ask pupils what they find interesting about science and construct curriculum round this. (ROSE Questionnaire)
Disjointed school curricula 5-14, SG and Highers	The links between the 5-14 and SG and Higher should all be improved.

Forming links across the curriculum is one of the themes stressed in the Curriculum Review and this should lead to a more integrated curriculum from which the pupil will benefit. There is a need for more integration in the sciences, both to prevent duplication and confusion and also because in industry and research more and more of the work is at the boundaries between the sciences. Important links can also be made with mathematics and English to improve general skills through reinforcement and to apply these to the benefit of education in the sciences. Less obvious are possible links between the sciences and subjects such as geography, history and modern studies. Climate change is relevant to both science and geography and could also be discussed in modern studies. There are also strong links between history and the sciences that could be explored. At present it is not known how this cross-curricular activity will be achieved but there are lots of possible avenues to explore, from teachers simply getting together to arrange the timing of similar parts of the curriculum to the allocation of a free week when a cross-subject project could be undertaken. We believe this could greatly enhance pupils' school experience.

A summary of the main findings is given below for each of the other subject areas. More detailed comments are in Appendix C.

3.v. Mathematics

Mathematics is seen as perhaps the most important school subject by lecturers in engineering and the physical sciences and also increasingly in life sciences which are becoming significantly dependent on the use of mathematical tools and analysis.

Mathematics is the one area in the school curriculum where a reduction in content is not desirable and indeed there are requests for the introduction of more statistics somewhere within the school curriculum. Some engineers, mathematicians and computing lecturers would like more geometry introduced, both for its application and also to introduce students to the idea of a proof. However these pleas are secondary to the wish for better mastery of algebraic techniques and for an understanding of the concepts of logarithms, exponentials and indices.

Even well qualified students have difficulty with algebraic manipulation and, according to school mathematics examiners, this has been a problem for twenty years. Skill in manipulation is required in the solution of most mathematical problems and so it is a vital skill which requires to be developed more fully. It is suggested that more work is done on fractions, ratio and proportion in primary schools so that the foundations can be laid for the introduction of algebra in secondary school. Time is required for the acquisition of new skills and it seems that the present system may introduce the above concepts to some pupils only a short while before introducing algebra.

With more students going to university the pool of students taking mathematics has perhaps widened and it *may* be that different teaching and assessment methods should be made available for some if not all. There is evidence that a more applied approach to mathematics motivates and stimulates the interest of some students. When students see the relevance of mathematics to a particular situation they are more prepared to become engaged with the problem and to find the solution. At Paisley University a more applied approach to mathematics is used and students appreciate and thrive on this method of teaching. There have been suggestions that a more applied approach may improve mathematics teaching in schools.

We believe that there might be significant scope for some mutually beneficial reinforcement between the teaching of mathematics and that of science. Science courses could take deliberate advantage of techniques and skills as they are developed in mathematics, supporting and bringing more relevance to these and providing applications of them in action. For science itself this would make a significant contribution towards strengthening mathematical and problem-solving skills. In some areas science could provide some starting ideas which might later ease the path for further development in mathematics. We have argued elsewhere for emphasis to be given in science to scale: introducing such quantities as the size of an atom or the diameter of the solar system leads immediately to writing numbers in scientific notation: the powers of ten are the most significant factor, and in this lies the roots for future work with logarithms and indices. Science also provides opportunities for introducing some basic ideas for later development through statistics: many have argued that the concept of risk should be introduced, a probabilistic concept central to discussing science 'issues,' and there are very many areas which deserve attention to determining 'average' values and some measure of distribution.

Some university mathematicians have expressed surprise that computers are not used more in the teaching of mathematics at school as a means of aiding understanding. While some software packages are available, there may be a need to develop more suitable packages. One of the main impediments to computer use, in some schools, appears to be the non-availability of computer rooms to mathematics departments.

The main points raised during interviews are summarised below:

- The syllabus content is important in this subject and the current syllabus matches the needs of the universities. The option offered for Unit Three in the Higher is not popular as key mathematical topics are sacrificed if the Statistics unit is chosen. Ideally there should be some statistics in the mainline course.
- There should be more practice in and a strengthening of the basic principles.
- There is a need to improve mathematical skills, especially in basic algebra (this is the most important skill of all), indices, logarithms and exponentials.
- Alternative teaching and assessment methods should be investigated (including computer use).
- The introduction of some additional geometry to the course should be considered along with the idea of proof.
- There should be improved congruence between 5-14 and Standard Grade curricula.
- Mathematics should be integrated into other areas of the curriculum.
- Topics are presented in isolation from their applications. A more applied approach to the teaching of mathematics would be welcomed.

Deleted: ¶

3.vi. Computing and Information Studies

The existing Higher Computing (as offered until 2004) does not adequately equip students with the skills and aptitudes necessary for entry to a computing science degree course. In Higher Computing there is a very superficial cover of 'almost the whole of computing' and this appears to have the effect of switching the students off when they come to university as they think that they have already covered all the topics at school and find the nature of the discipline very different from what they anticipated on the basis of school experience. They are unaware of the analytical skills they must apply, most particularly in developing programming skills.

A review of the current computing courses in schools has been carried out by SQA and the new Highers in Computing and Information Systems are now available. It is unclear at present if the new Higher in Computing adequately addresses the needs of the universities. Universities would like pupils to have an understanding of the basics of programming and at present regard Higher Mathematics as a better indicator of student suitability.

There is a large gender imbalance in computing science courses at universities. This is even more marked than the gender imbalance at school. Ways of making school computing courses more attractive to females should be considered. We discuss gender issues in a later section of this report.

There appear to be problems getting qualified staff in schools to teach computing and to keep their skills up-to-date.

The Advanced Higher is perceived by the SQA as the link to university computing science courses, but not many pupils take an AH in either Computing or Information Systems. Scottish university degree courses are designed to be accessible from Higher and it is important that Higher Computing should reflect the nature of the university computing science.

Lecturers think that there should be more emphasis on basic programming skills in the Computing Higher, and that the suitability of the new Higher should be monitored. Again it appears that the school curriculum in this area covers a lot of ground, in perhaps a rather superficial fashion, and it may be better to study fewer topics and more extended exercises in more depth and so gain a better understanding of the subject and build up the required skills.

3.vii. Technological Studies

Recognition of the Higher seems to be the major problem here. The Higher curriculum *appears* both academically rigorous and relevant but it is not highly regarded in schools and it appears pupils are urged to regard Higher Physics as the sole 'respectable' preparation for engineering. There are serious concerns about very low uptake, and teacher availability.

Most, but not all, divisions in engineering faculties will accept Higher Technological Studies in place of Higher Physics for university entry, but generally university engineering admissions staff tend to mirror the more broadly held perception, perhaps influenced by experience, that higher achieving pupils at school tend to take Physics rather than Technological Studies. If students entering university to study engineering have a Higher in Technological Studies they tend also to have a Higher in Physics.

There appear to be many reasons why the subject is not popular in schools at either Standard Grade or Higher. One of the main reasons appears to be that in trying to please everyone it pleases no one. It is neither a purely practical based course nor an academic course, but something in between.

The subject is not well publicised and class areas where courses are taught may not be attractive. Also, in schools Technological Studies may not get the resources required .

There is evidence that if a thematic approach is used this could be successful. The course has been successfully taught using a robot kit as a means of introducing all the course material. This appears to have motivated pupils. In the Aberdeen area industry has invested in and been involved with pupils on the course and this has increased its popularity. An applications led approach[22] also helps to engage students in the 10-20 year age range far more than other forms of teaching. The actual way in which the curriculum is written makes a huge difference e.g. SG Physics in Scotland. This is something that should be considered for other subjects such as Technological Studies.

It may be useful to look at the syllabus for engineering courses in other countries where such courses are popular. Eire is such a country, but although large numbers take these courses not many progress to university to study engineering. Technological Studies, as the only subject in schools which gives pupils any idea of what engineering actually is about, needs to be reviewed. Consultation with industry and subject teachers in schools may help clarify the purpose and aims of engineering courses in schools as this seems to be problematic at present.

As the 3-18 Curriculum Review advocates both subject-based studies and activities which span several disciplines it may be that a way of making technology more relevant would be to integrate it with more science based subjects as well as the practical aspects of engineering

The teacher has obviously a very important role to play in motivating and attracting pupils. We need to consider the learning pathways, teaching resources and pedagogy (including ICT) and whether they are fit for purpose. Continuing Professional Development (CPD) for teachers is important as also is providing material which will help the subjects be more interesting and relevant.

Lecturers think that most pupils do not know about the career options open to engineers and think that career opportunities information should form part of the school curriculum.

3.viii. Product Design

This Higher has been redesigned for 2004/2005. It was formerly called Craft and Design and attracted about 2500 pupils for the Higher annually. Not many students entering the University of Glasgow to study science or engineering degrees possess this Higher. Of students who graduated in 2004 only 14 of those who who gained a science degree and 26

[22] Reid, N and Skryabina, E, *Attitudes Towards Physics*, Research in Science and Technological Education, 2002, 20(1), 67-81.

of those who gained an engineering degree possessed this Higher. All students who possessed this Higher also had a Higher in a science subject.

Some universities, which offered engineering courses in product design, like both the new and existing Higher and accept it as a Higher for entry qualification.

3.ix. Graphic Communication

This is a subject which is increasing in popularity with the numbers sitting rising from 2522 in 2000 to 3246 in 2004. Again, Not many students entering the University of Glasgow to study science or engineering degrees possess this Higher. Of students who graduated in 2004 only 18 of those who gained a science degree (including computing) and 38 of those who gained an engineering degree possessed this Higher. All students who possessed this Higher also had a Higher in a science subject.

4. Science for all.

What does the university STEM community believe is most important in the school education for those not on science-based careers?

There is support from lecturers for pupils to study science at school so that those who perhaps do not want to pursue a career in science would still acquire sufficient knowledge of scientific principles to enable them to begin to make informed assessments of important contemporary scientific issues. It is also thought that these issues should be raised in schools and pupils should be able to research for information and draw conclusions from the data obtained. There is need for a course or a major strand integrated within science education, called here "Science in Society" in which these issues are discussed. The science knowledge required for such a course should also be taught. The following paragraphs give an indication of the rationale for such a course and how it could be constructed. It is envisaged that all pupils would undertake a course of this nature and that it could be run at several different levels.

4.i. Science in Society

When looking at the current arrangement documents for science subjects it is striking that two topics of great importance are not mentioned:

1. how much the application of science has transformed our lifestyle in the last 200 years and
2. issues about science that appear in the press today.

It is important for all to understand how much our standard of living has improved in the last 200 years. Without people such as Newton, Dalton, Faraday, Watt, Darwin, Babbage and Mendel we would still be living an uncomfortable existence in cold, damp housing, be poorly fed and live shorter and often less healthy lives, and with no mechanised transport, home entertainment etc. The kind of life we live today is due to the advances made in science and engineering.

Science in school is all about basic groundwork. The issues raised about science in the press today are not addressed. Issues such as potential applications of stem cells, BSE, mobile phones, nanotechnology, GM foods, alternative and conventional forms of energy and environmental policies more generally are not discussed in the classroom.

These issues generally raise the same central questions:

- Can we be sure that we use reliable evidence to help us make the best choices?
- How do we assess the risks against the benefits involved in the different choices?

It is important that all our young people, both the future scientists and the non-scientists, have some understanding of the how science has transformed our lives and can continue to be of benefit to our lives in the future if correct and informed decisions are made. Young people should feel able to participate in debates on subjects of controversy, with some sense of the background and of the balanced analysis required to make informed judgements.

How can these issues be best addressed and how can the whole school population be included?

A possibility is that a *Science in Society* strand could be offered as a core component in the curriculum. This would run in parallel with more traditional science courses which would give most of the basic grounding to cope with a *Science in Society* course (a possible list is given below under the heading "Science explanations"). It is envisaged that this strand would run through the secondary school from S1 through to S5 and that the course would utilise the developing understanding of the principles of science in pupils as they progressed through school. Each pupil would be able to study a level of *Science in Society* that was appropriate to the level of the general sciences he was studying. There is also a case to be made to widen the remit of the course to include aspects of technology, as this is an area neglected in schools.

What would be the aims of such a course?

The student should be able to:

- appreciate and understand the impact of science and technology on everyday life;
- make informed personal decisions about things that involve science and technology, such as health, diet, use of energy resources and technology;
- read and understand the essential points of media reports about matters that involve science and technology;
- reflect critically on the information included in, and omitted from reports and
- take part confidently in discussions with others about issues involving science and technology.

(These aims are not original but taken with slight modification from 21st Century Science[23]).

To be able to "appreciate and understand the impact of science and technology on everyday life" the pupil will need to have some understanding of the major ideas about science and science explanations.

4.ii. Ideas About Science

People need an understanding of the major ideas of science and to do this they must be able to look at the kind of reasoning that is used in developing a scientific argument and at the issues that arise when scientific knowledge is put to practical use. This will involve developing understanding about:

- theories
- data and its limitations
- correlation and cause
- risk and
- making decisions about science and technology.

[23] 21st Century Science. http://www.21stcenturyscience.org/home/

4.iii. Science Explanations

To have a grasp of the theories of science the following list of subjects is thought to be essential:

- Chemicals – atoms and molecules
- Chemical change – linked to rearrangements of atoms
- Materials and their properties – linked to atomic composition and molecular shape
- Cells as the basic units of living things
- The interdependence of living things
- The chemical cycles of life
- Maintenance of life
- The gene theory of inheritance
- The theory of evolution by natural selection
- The germ theory of disease
- Responding to stimuli
- Energy sources and use
- Mechanics
- Radioactivity
- The earth
- The solar system

It is suggested that such a list of central ideas is adopted and highlighted and that the level of understanding of each is progressively deepened through the science subjects taught from S1 through to S5.

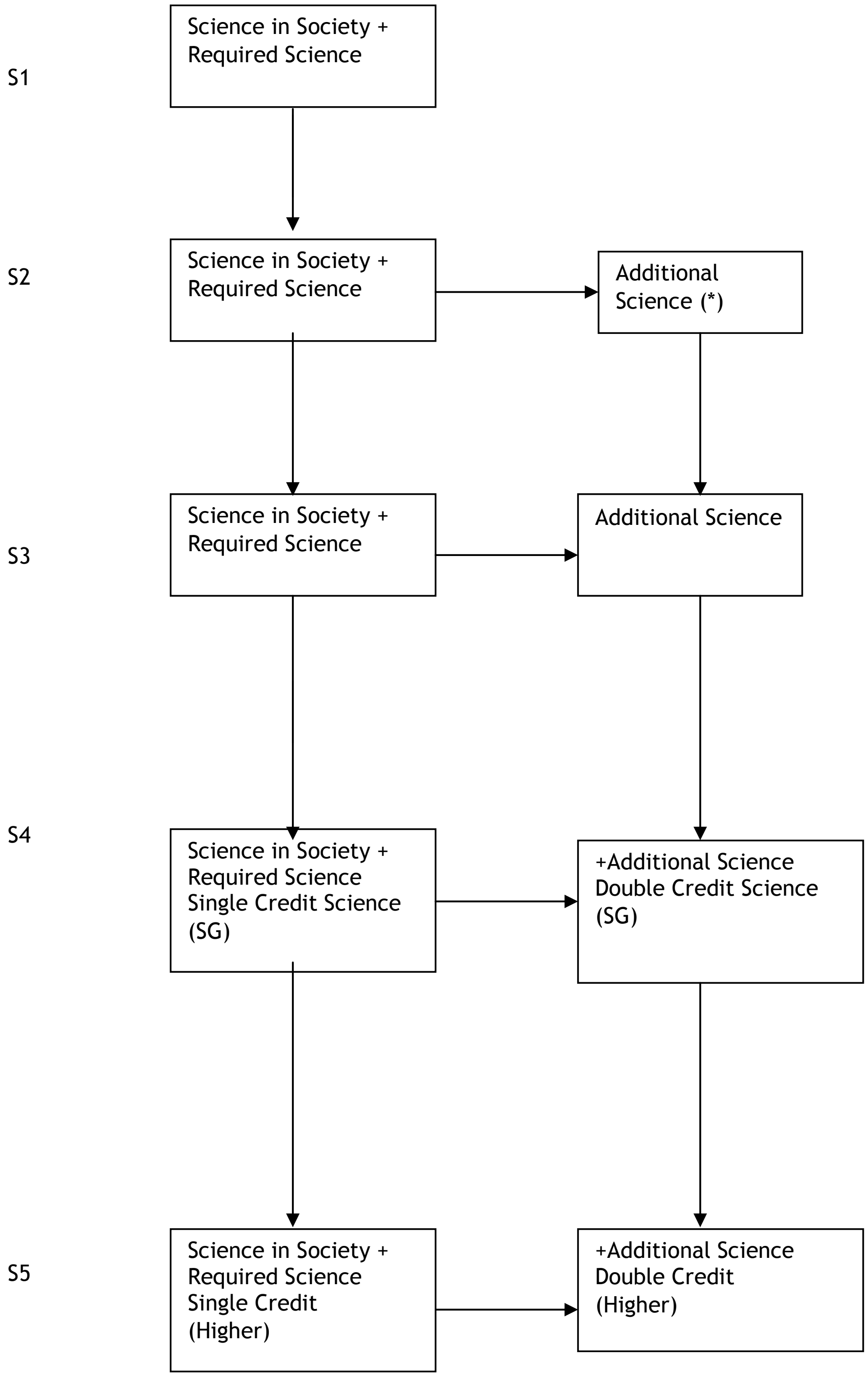
4.iv. Scientific Literacy.

It is not the purpose of this project to give an answer to how this Science in Society course is delivered, how many hours/ year should be allocated to it, how it should be delivered, assessed or what its detailed content should be. However, the university community believes strongly that there is a need for such a course for the would-be scientist and also the non-scientist. If this is the case, for this course to be meaningful, it will be necessary to redesign existing science courses to ensure that the basic scientific ideas required are taught. We also see the introduction of Science in Society as being a way to encourage pupils into science and as a possible way of improving overall literacy, for instance, by requiring pupils to produce a report on a particular issue. Science in Society could be taught as a separate subject strand or it could be integrated within reshaped separate science courses.

As pupils and students tend to compartmentalise knowledge, and whilst nowadays very many of the exciting and promising frontiers of science are interdisciplinary, there has been some support for the three sciences to be merged within the school curriculum, although lecturers have emphasised that the different components of any science course should be taught by the subject experts. To the extent that such moves are made it would seem sensible to embed also the "Science in Society" strand so that science could be developed as a coherent whole.

The proposed framework for Science in Society is illustrated overleaf.

English, mathematics and science are core subjects at present up to S4. Lecturers would like this to continue with a single science subject being offered to all. As with the present curriculum there could be different levels designed to meet all pupil needs. Those wishing to pursue scientific careers could opt to take an additional science subject, which would then offer additional chemistry, physics and biology. This would correspond to a double credit in the sciences and would be equivalent to two sciences at Standard Grade. Pupils who go on to take science Highers might again have the possibility of a double credit, again including the three sciences plus an element of Science in Society. As it is not known at present whether Standard Grades will still exist, whether it will be possible to start Higher work in S4 or how many Highers a person will take it is difficult to say if a double Higher of this type could be constructed to suit the needs of universities but, in principle, the idea of a double credit Higher in Science seems sensible. The possible model is illustrated overleaf.



Single Science award Double Science award at SG and

Higher.

*If it is decided to start post 5-14 in S2.

At Advanced Higher level single subjects would be offered with applications, issues and an extended project.

To summarise:

- A major course or strand (provisionally called "Science in Society") dealing with science issues should be introduced for all school pupils.
- Two topics should be included: how the understanding and application of science has altered our lives and issues about science that appear in the press.
- This course may be combined with the recommended underpinning science required for the course.
- The subject should be taught from S1 to S4 or S5 and perhaps have some elements covered in primary school.
- Integrating the Science in Society theme in a single combined course structure should be considered.
- Pupils studying science should be able to take an additional combined science subject at Standard Grade and then progress to a single or double credit at Higher.
- The secondary science curriculum should be replanned in a coherent fashion, progressively to develop the major ideas of science, to address the relevance of science to society and issues of controversy, and to develop scientific skills and competences.

5. Concerns About STEM Subjects Uptake And Difficulty

Concern has been expressed at the numbers of well-qualified school leavers applying for university places in STEM subjects.

The numbers entering engineering and the physical sciences fell from 10.5% to 8.0% and from 5.4% to 4.3% respectively between 1995/96 to 2002/03. Graduates in these disciplines are required to help sustain and expand the Scottish economy so it is vital to attract more students to these areas. Given the still high, if declining, uptake of the Higher science subjects at school, it does not seem that the experience of these science subjects has the effect of encouraging progression at university.

Possible reasons why pupils do not pursue science subjects are:

- The present school curriculum is not seen as interesting or relevant.
- The subjects are regarded as difficult.
- The chances of gaining a Higher, or a better grade of Higher, are greater in other subjects.
- Schools and teachers are worried by their position in the league tables published by the Press and this makes them focus on exams to the detriment of exploring implications and applications.
- Pupils do not know what engineers and scientists do, and generally the image of engineers and scientists is not positive.
- Careers teachers generally do not seem to recommend the study of engineering at university and prefer to steer able pupils towards the medical and legal professions.
- The environment in which a subject is taught is important and generally school laboratories and workshops compare unfavourably with say computing laboratories.

5.i. Numbers Taking Science Highers

The numbers taking Higher Biology, Chemistry and Physics are dropping. There has been a drop of approximately 5% in these subjects in the last two years. There has been a substantial increase, however, in the numbers taking Higher Human Biology, which has risen from 2837 to 3296 in the last two years, although the trend in biology is still downwards if the two subjects are counted together.

Between 1995 and 2003 the drop in numbers of those sitting science Highers is even more striking. There has been a drop of over 20% in the three sciences with only Higher Human Biology showing an increase in numbers. However, even if Biology and Human Biology are considered together the overall trend is still downwards (13%)[24].

The number taking two science Highers at one sitting has fallen dramatically from 13% to 9% in 4 years and for the number taking three sciences the fall has been from 2% to 1%. The most popular combination is Chemistry with Physics, followed by Biology with Chemistry. Medical students usually require at least 4 A Highers, two of which will be Biology and Chemistry. These students commonly account for one half of pupils with these Highers. This tends to mean that science and engineering faculties are deprived of many able students and that the science faculties in universities can seldom now insist on a student having two Highers in science for entry to their courses.

Students entering the physical sciences and engineering require a Higher in Mathematics and either Physics or Technological Studies. There are sufficient pupils leaving school with the qualifications required. The key problem here is that of the students taking Physics at school not enough choose to pursue these subjects at university.

Scottish industry thinks that it will have a shortage of engineers in the future and does not think that we are training enough of our own people either at graduate or apprentice level. As can be seen in Appendix I the numbers taking Technological Studies have never been large and have dropped by 13% in the last eight years. Students who enter university with this Higher nearly all possess Higher Physics as well, so it is difficult to estimate how this subject is rated as an acceptable Higher in its own right.

5.ii. Relative Popularity of Subjects at Higher and Standard Grade

Higher Physics is a popular Higher in Scotland (in 2002 it was third after English and Mathematics, see Appendix I). This goes against trends in Europe and elsewhere where the numbers are falling even more rapidly. Research[25] has shown that Standard Grade Physics has been very popular in Scottish schools because the course adopts an applications led approach that pupils appear to enjoy. They understand its relevance to their own lives and are interested in the subjects dealt with. Pupils then want to study the subject further and progress to Higher Physics. Here they come across a more classic type of curriculum which does not enthuse many to pursue physics or engineering at university.

If the Higher course were applications led would this encourage more pupils to go on to university to study physics? Physics is regarded as a “hard” Higher and so students are not encouraged to progress to the subject at university fearing that it will get even more difficult.

Pupils do not feel that the science courses, with the possible exception of physics, offered at school relate at all directly to everyday life. Issues that they read or hear about in the news concerning science topics are never discussed in the classroom. There is evidence to show that pupils would like to discuss these issues at school and would like to be able to make informed judgements on these kinds of issues.

Mike Tomlinson[26], who was chairman of the 14 – 19 Review in England and Wales said recently that if science education is to recover from its recent downturn in popularity

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[24] See Appendix I

[25] Norman Reid & Elena A Skryabina, 2002Attitudes towards Physics, Research in Science and Technological Education, Vol. 20, No 1, 2002.

[26] http://www.21stcenturyscience.org/news/n0000000874.asp

among students, the country must once again trust its science teachers. He stressed that any science curriculum should have:

- ethical and moral discussion as part of lessons, alongside the development of scientific knowledge, i.e. there should be a better balance between scientific literacy and scientific competence;
- a reduced burden of summative assessment and improved assessment for learning;
- more time for teaching and learning;
- a more intelligent system for public accountability in education, at present only what is measurable is valued and
- more subject specific CPD for teachers.

This seems to encapsulate a lot of what we have heard from lecturers in Scotland.

Mathematics is also regarded as being remote from everyday life and if more connections were made it may help improve interest and help students see its relevance to their lives.

The Robert's Review[27] found that there is a "disconnect" between the demand for graduates in mathematics, engineering and physical sciences on the one hand and the declining number of graduates in these subjects.

Issues that were identified in the review for this disconnect are:

- fewer females choosing to study these subjects at A-level (Higher was not mentioned) and
- poor experiences of science and engineering education at school and inadequate information about careers.

In Scotland there are perhaps more females studying mathematics and the physical sciences at school than in England and the gender issue is discussed later.

Lecturers believe that pupils do not realise the full extent of the careers open to those who take degrees in science and engineering and would like science courses at school to explicitly highlight the career relevance of subjects. Education specifically for the engineering profession in schools is problematic in Scotland and has been discussed in more detail in the section on Technological Studies. The numbers taking Technological Studies are falling, both at Higher and at Standard Grade. There has been a fall of 38% in the last four years at SG whereas the numbers have been fluctuating year on year at the Higher stage. Perhaps one of the reasons for the unpopularity of the Higher might be due to reactions to the course at Standard Grade level. Further research needs to be done to find the best way forward with this subject. Representatives from industry need to be asked what they want in the way of an introduction to engineering at school both for those wishing to take up modern apprenticeships and for those who want to become graduate engineers. The opinion of subject teachers in schools should also be sought as they are the ones who know the problems with the present qualifications.

Modern studies is a subject proportionally more popular at Higher than at Standard Grade. Is this because pupils are maturing and more interested in the contemporary world or do they like the type of class where topical issues can be discussed and debated? Would the introduction of science subjects that are discussed in the news make the sciences more relevant and hence increase uptake?

5.iii. Issues Related To Subject Difficulty.

National Ratings (see Appendix I) are a measure of the relative difficulty of school subjects. The more negative the number the greater its perceived difficulty. The ratings are worked out annually and fluctuate from year to year. Average ratings taken from the start of the Higher Still Highers (2000) show that, of subjects normally offered at school, Chemistry has

[27] SET for Success: The supply of people with science, technology, engineering and mathematics skills. The report of Sir Gareth Robert's Review, April 2002

the highest negative value of National Rating and hence difficulty. This is followed closely by Mathematics and then Biology[28].

Looking at pass rates[29], Biology generally has a lower pass rate than the other two sciences.

In contrast, the NRs at Standard Grade show that Standard Grade Mathematics is rated more difficult than the sciences and that the science NRs at Standard Grade are significantly less negative in value than the NRs for the same sciences at Higher. This means that pupils find sciences significantly more difficult than other subjects at Higher, something they are unprepared for by their Standard Grade experiences. It is more difficult to achieve a Higher at a given grade in a science subject than in almost any other subject. The chance of gaining a pass at Higher in a science subject following a Credit-level pass at Standard Grade has also decreased in recent years.

Links between Standard Grade and Higher courses.

In 2002, the percentage passing Standard Grade at Credit level was 52% for Biology, 57% for Chemistry and 60% for Physics and if Credit and General passes were considered together the percentages passing were 87, 91 and 91 respectively. There are pass of 70 – 75% for the A-C grades in the corresponding Highers.

The figures below also show the relative inaccessibility of the STEM Highers for all but those pupils who have obtained the very top Standard Grade band. It has become progressively more difficult for pupils with Grades 2 and 3 at Standard Grade to achieve a pass at Higher in the same subject but these effects seem particularly severe in the sciences. When averaged out over 20 subjects in 1993, the chances of a candidate passing a Higher with a given Grade of Standard Grade were:

SG at Grade 1	95% achieved a Higher pass
SG at Grade 2	67% achieved a Higher pass
SG at Grade 3	34% achieved a Higher pass
SG at Grade 4	18% achieved a Higher pass

In other words candidates with a Grade 1 were virtually guaranteed a pass at Higher and with a Grade 2 there was a two-thirds chance of a Higher pass. These average figures however mask the differences between subjects as can be seen from the table below and when results are compared with those of 2002 the picture is further altered[30].

[28] See Appendix I, tables 6a – 6c
[29] See Appendix I, table 7
[30] Progression from Standard Grade to Higher and from Higher to Advanced Higher. Bulletin number 6, SQA 2003.

Table 2: Pass Rate for S5 Higher based on performance at Standard Grade the previous year

Subject	Grade 2		Grade 3	
	1993	2002	1993	2002
English	82%	66%	41%	34%
Mathematics	58%	37%	21%	17%
Biology	53%	37%	21%	17%
Chemistry	59%	38%	15%	14%
Physics	51%	45%	10%	11%
Computing	60%	57%	19%	25%
Technological Studies	51%	51%	8%	17%
Economics	82%	79%	46%	63%
Art and Design	91%	79%	63%	52%
Average for 20 subjects	67%		34%	

In arts type examples the chances of gaining a Higher with either a Grade 2 or 3 at Standard Grade are much higher than in science and technology subjects and this may be one reason why pupils are discouraged from attempting science and technology Highers and encouraged to take a subject where they have a much better chance of obtaining a Higher. Ideally there should be a smoother transition from SG to Higher in all subjects and it should be possible to progress from SG to Higher in one year with an equal chance of success irrespective of the subject studied. The structure of the Higher examination changed between 1993 and 2002 with the introduction of Higher Still qualifications but much work needs to be done to enable a smoother transition between the Higher and whatever its chosen precursor becomes. It cannot surely be regarded as appropriate that a pupil who achieves a Credit at Standard Grade (if it is a Grade 2 Pass) has barely more than a one-in-three chance of passing the Higher if the subject is Biology, Chemistry or Mathematics.

There is evidence that some schools are beginning to offer the Intermediate 2 qualification to S4 pupils instead of Standard Grade as it is regarded as a more demanding course and may better prepare a pupil for the Higher. This is illustrated by the National Ratings for Intermediate 2 and Standard Grade (See Appendix I, Table 6a-c for SG, Higher and Int 2 NRs).

Higher Still Highers

There are three units in most Higher courses and each of these has an end of unit assessment (National Assessment Bank - NAB) which the pupil has to pass in addition to the final examination. These NAB assessments consist of much more straightforward questions and obviously just examine the work of the unit. This is not good preparation for the final examination.

The great difference in the level of difficulty between the SG and the Higher in the sciences, coupled with the comparative ease of the NAB assessments, does not prepare pupils well for the final examination. In any review of science courses at school and the assessment process consideration should be given to these two factors. A way must be found to provide a more smooth transition between levels and consideration should be given to offering the Higher course as a uniform course rather than fragmenting it into units.

5.iv. Gender Issues.

This was not an issue we initially envisaged highlighting but as work progressed it appeared that there were particular subject areas of the curriculum where gender was an issue worthy of explicit analysis in any review. Overall, in Scotland, for Higher entries the ratio for female /male is 55/45. The reasons for this are not clear and should perhaps be investigated. In 2002 the proportion of female/ male entries for Highers in Mathematics, Physics, Chemistry, Biology, Computing And Technological Studies was: 48/52, 28/72, 50/50, 75/25, 26/74 and 6/94. So, while almost equal numbers study Mathematics and Chemistry, girls are not choosing to study Computing, Physics or Technological Studies and boys seem to steer away from Biology.

In Scotland physics is a popular choice and more females study the subject than in many other parts of the world. There is found to be a positive attitude to physics by both boys and girls up to S1. Physics is a popular choice at SG and Higher and many more females study the subject than elsewhere in the world. The subjects listed above are traditional subject areas for gender inequalities and this report offers no specific or novel solutions on how or if this situation should be remedied, although perhaps the results of the research referred to below for computing may suggest an approach worth investigating.

Computing

When looking at computing science courses in universities we were curious about the gender imbalance and decided to pursue the topic further. Gender ratios for most subjects are broadly consistent between the Standard Grade and the Higher, except in the case of Computing where the ratio is 36/64 at SG, worsening significantly further to 24/76 at Higher. At university the proportion of females taking computer science is no greater than 15%. So females are being progressively switched off from Computing from SG to Higher and then to university.

Strangely, on postgraduate degree courses in computing there is a much increased proportion of females. They perform as well as their male counterparts although it has been noticed that if there is a project involved with the course the type of project chosen will differ. Females seem to prefer constructing programs involving design or with a more human perspective. The present earlier curriculum perhaps appeals more to males rather than females. It is not clear why females do not find computing an attractive option, but they seem to gradually turn away from the subject from Standard Grade through to university. A good pass in Higher Mathematics is regarded as an indicator of ability in a computing science course and on looking at the Higher results it is seen that females achieve as many grade A passes as males. Their capability to enter the course is not in doubt, it is their interest that has not been aroused.

The poor progression in interest through school may relate partly to the physical equipment and surroundings but surely also to the ability of the course to inspire and interest pupils, and particularly girls. Perhaps research into this area may also help overall to attract more students.

Research[31] has shown that while women use the internet for communication and the web for information retrieval as frequently as men, it is mainly men who are programming the computers, designing and fixing the systems and inventing the technology that will affect all aspects of our lives. This lack of women being involved can have serious consequences for a society that is increasingly shaped by technology. It means that for example new gadgets will be developed with only men in mind and so attract even more men to computer use. It also means that some items are designed which are unsuitable for women and children. This was the case with the first car seat belts which were designed by men to fit men.

In universities typically only 10-15% of students entering computing courses are female. Female students are also about twice as likely to drop out of undergraduate computing courses as their male counterparts (note the contrast with the equality in performance mentioned above for postgraduate ‘conversion’ courses). One of the reasons why students

[31] Unlocking the Clubhouse: Women in Computing, MIT Press, 2002, ISBN 0262133989

drop out is because they lack confidence in their abilities. They come to university often with less computing hands-on experience than some of their male "geek" counterparts who may have been obsessively involved with computers during their teenage years. Females do not think that they can compete with these males as they are not so driven and so obsessed by computers. The curriculum in a lot of computer science courses also tends to be orientated towards the appetite and learning styles of the male student.

Male students express their interest in computer science by focussing on the computer alone whereas females are more interested in computer science within a larger purpose. For example a woman would say that she wanted to be in computing to work in environmental pollution. Women are attracted to "computing with a purpose" whereas men are attracted to programming for programming's sake

It seems that the number of women programming has decreased over the last thirty years. Before computing degrees became available entry to programming was by sitting an aptitude test after taking a mathematics degree. At that point there were a lot of female programmers, reflecting the much better gender balance still prevalent for those entering computing at postgraduate level.

As women come to computing with different motivation then this has implications for the way programming is taught and the type of examples being used. By using a more multidisciplinary approach and choosing suitable examples it should be possible to attract more females. Using the results of research at Carnegie Mellon University[32] the computer science department there managed to increase women's enrolment from 7% to 42% within 5 years. They did this by attempting to teach computing in a more interdisciplinary way and also by taking into account the different levels of experience of entrants. Often women were inexperienced but did not lack ability. If they were put in a group of the same experience they were more motivated and did not get so discouraged. At the end of the first year all groups had reached the same standard.

At school computing is less popular with females than with males and this trend is more marked at Higher than at Standard Grade. Whether the lessons learned at Carnegie Mellon University would apply in a school context is difficult to say but selecting wider applications for computing that may appeal more to females may be a step in the right direction. Another way to encourage females who may not have as much experience as the males is to divide them in the class into groups of roughly similar experience so that individuals are not discouraged by those who have had more hands on experience.

Technological studies

Technological studies is a subject that while it is not attractive to girls seems to be losing its appeal for boys also and so the problems here are not just related to gender. The gender imbalance here presumably reflects that suffered by engineering as a whole, perhaps to do with old-style perceptions of the heavy manufacturing industries and a lack of appreciation of the nature and breadth of roles in the modern profession.

A questionnaire, issued to school pupils a number of years ago, was designed to see what were the perceptions of boys and girls of the word "technology". The boys responded in the expected way naming computers, tanks, planes, robots and space age stuff etc. Girls, on the other hand, responded mainly in contexts of society, the environment, health and welfare and making lives better and safer etc. Again it may well be that careful choice of the range of applications introduced at school, from the 5-14 Technology strand onwards, might influence perceptions.

To summarise:

- Efforts should be made to halt the downward trend in the numbers taking even one Higher in a science subject and the study of at least two science subjects at this level should be encouraged in an effort to maintain numbers entering STEM related degrees at university.

[32] http://www-2.cs.cmu.edu/~gendergap/

- To encourage more pupils to study Highers in the sciences and in Technological Studies, the content, attractiveness, and relevance of the Standard Grade should be investigated, as this is what may decide a pupil's interest in a subject.
- Ways to improve science Higher courses may also be found by reviewing other subjects popular at Higher. Pupils should be surveyed to gain intelligence on what topics and approaches might raise interest: the ROSE questionnaire[33] has been designed and used internationally for this purpose. Ways should be looked at to make courses more relevant and interesting to both male and female pupils.
- The decrease in uptake of the science Highers must also be due to the difficulty of the subject at Higher compared to the comparative accessibility of the Standard Grade.
- Work should be done to enable a smoother transition between Standard Grade (or its successor) and the Higher in a subject.
- It should be possible to progress from SG to Higher with closely similar prospects of success in all school disciplines.
- Higher end-of-unit assessments, in their present form, appear to be unproductive and do not prepare pupils for the final examination.

6. Assessment

In the course of our discussions assessment has been identified repeatedly as a critical area of concern. It is generally believed that school courses are assessment driven. We feel that the current assessment regime adversely influences both the nature of the education delivered and pupil attitudes to learning and to the subject itself.

There is intense media interest in league tables, with significant impacts on an individual school's public reputation, and there is a natural drive to see robust evidence of rising pupil attainment levels. Very many teachers see performance in the public examinations as the key criterion by which their performance is judged. It is hardly surprising that this generates pressure to teach with the examination always very much in mind. Universities too are a contributory source to these pressures, particularly where they may have focussed on specific subject grades for entry to a course.

The nature of the examinations themselves can exacerbate the negative educational effects. Assessment is a process of judgement and an examination is a mildly imperfect measuring tool (pupils would not all achieve exactly the same marks if an alternative equally well-designed and appropriate question paper were used). On the other hand judgements made in marking each individual script are in principle nowadays always open to being questioned and it is advantageous to have a water-tight defence of the decision made on the allocation of every individual mark. This makes it much more amenable for the examiner to set questions with very specific "right answers" for each and every mark to be awarded, than it is to set an open and extended exercise, such as an essay, where many different approaches may be taken by different candidates, and where different markers could reasonably differ marginally on the precise mark justified. Succumbing to the more amenable path does, we believe, carry significant educational penalties.

Learning concentrated on detail, and training in handling a large number of specific short problem tasks, provide easily specified and robustly assessable outcomes. The science curricula greatly emphasise such details, and they dominate examinations. Many of us have heard anecdotally from teachers that they feel the overwhelmingly important criterion they face is to maximise examination success. In this context they feel under an onus to direct almost all teaching effort to addressing the specifics of the curriculum, to the detriment of available time to develop the larger picture and to trace implications and connections that contribute towards building a broader understanding and developing key transferable skills.

[33] http://www.ils.uio.no/forskning/rose/

The heavy focus on examinations, and the highly specific nature of what is assessed, can also colour student attitudes to learning. A largely one-to-one correspondence between atoms of learning and specific exam questions can tend to frame their future expectations in education, that every learning effort should be directed to, and exerted in proportion to, a clear and specific assessment credit. The topics themselves can be viewed as of limited relevance, representing minutiae that can safely be forgotten once the relevant assessment is past. The coherence, beauty and power of the subject itself surely risks being lost on the learner who might see it as a collection of apparently weakly connected topics, most of which may seem to be of limited interest.

There seem to be strong indications that schools are suffering from assessment overload. Pupils are tested at two levels in Standard Grade and they must pass all the unit assessments in the Higher courses plus the final examination. Students at universities now also seem more assessment driven than previously and this may reflect that "getting a degree" is much more of a motivational drive than an interest in the specific subject.

There is no evidence that repeated testing improves performance. Indeed for some pupils the opposite is the case. There is evidence that repeated testing causes under-achievers to perform less well.[34]

There appear to be concerns about national testing in primaries, as illustrated in the following quote from a Dundee primary teacher: *"I think that one of the worst things that has happened in education is 5-14 testing. I think the testing in primary school is absolutely at the crazy stage now. We're all given these targets that we have to reach. And in order to reach these targets we have to teach to pass the test. Teaching shouldn't be about passing tests. It doesn't matter how many times you weigh the cow, the cow's never going to get any fatter, just because you keep weighing it. It's what you teach that's important, not how many tests that you give these children."*

Assessment emerges as one of the key areas of the project. Most of the Highers in the STEM area are graded on the marks obtained in the final examination, although pupils will also have obtained a pass in each of the NAB assessments for the individual units of the course. At present university entry relies very heavily on the grades obtained at Higher. Whilst the numbers of Highers and the grades obtained will always be important for gaining university entry, the methods of assessment could be altered substantially so that a more holistic approach to assessment could be taken enabling the volume of assessment to be reduced. The examinations should also be redesigned to assess skills and understanding of basic principles much better.

At university, final grades do not depend solely on the end examinations. Other elements contribute, such as laboratory work and many different forms of assignments. These exercises encourage and assess a different mix of generally broader skills, including skills of key importance in research and other professional roles. They generally involve more extended exercises than can normally be handled in formal examinations. Most academics would accept that individual marks in such exercises are often less robustly reliable than, for example, student scores from a set of multiple choice questions. Indeed, there is often some small degree in uncertainty in the individual scores awarded to more open questions in formal examinations. This does not, however, prevent the use of these assessment tools, for great confidence remains in the overall results achieved by different students. A student's degree outcome arises from the combination of very many scores in individual exercises and exam questions: whilst there might be a small element of uncertainty about the precise validity of one individual component mark, the fundamental laws of statistics ensure that such individual random imprecisions shrink to insignificance in the aggregate result. One cannot test reliably whether a coin is "true" by tossing it only twice, but a test of a hundred throws gives much stronger evidence.

We have become aware that universities, through their specification of entry requirements, could themselves be thought to be an obstacle to significant reform at Higher and Advanced Higher levels[35]. We have consulted on this issue amongst participants in our project.

[34] National Debate on Education, Qualitative research with stakeholders, 17 September 2002 http://www.scotland.gov.uk/library3/education/ndoe-00.asp

- We can assert without hesitation that our project participants would not object to changes in assessment that led to much less detail-oriented examination papers. Nor would they be upset if not all corners of the topic curriculum were always addressed.
- Very many already make admissions decisions based predominantly on the total UCAS points score held by applicants rather than by reference to individual subject grades. They do of course typically require that certain subjects, or types of subjects, are included. We have found a consensus opinion that would be happy to rely on a much less onerous and less detailed school examination system, and particularly so if this is accompanied by changes in the approach to school course along the lines we advocate. Perhaps there would be advantages in greatly reducing the profile of individual subject grades in order to focus pupil and external attention on a single global aggregate assessment measure of school leaver performance over a given set of courses. Both our own recommendations for STEM subjects and the thrust of the broader *Curriculum for Excellence* Report[36] urge changes that would be facilitated by more emphasis on educational achievement in the whole.

We show in Appendix J that, whilst there is some correlation for university students between the strength of school leaving qualifications and their eventual degree classification, this is much weaker than may be widely assumed. School exit grades are a far from accurately predictable determinant of university performance. This further reduces any potential worries about a strategic review of the school assessment regime; it could well be that a simpler measure, more reflective of (and more nurturing of) broader knowledge and skills would provide a better measure of university level potential.

We are aware that individual records of achievement are being developed more fully rather than in less detail, and we can see the advantages in this in encouraging growth in self-confidence, reflection and motivation to progress. We would hope that this also encourages taking a holistic and strategic personal overview of achievement and development, rather than a simple "tick box" accumulation of fragmented items. We feel that universities could make their contribution to encouraging everyone to take a more holistic view if minimum entry qualifications for courses avoided requiring specified grades in individual named subjects in place of a broader statement such as: "You require a score of at least X UCAS points over five subjects including subject A and either B or C." This avoids any implication that a single examination grade is a matter of life or death, and in many cases it reflects actual current practice.

We would support a more relaxed and adventurous approach to assessment in schools. It could be healthy and appropriate to include scores from teacher-set and internally marked exercises, allowing a fair degree of initiative within some general guidelines, and supported only by a "light touch" mechanism for moderation. These could enable more open ended and extended exercises to be undertaken. The introduction of a report on a scientific topic would make the curriculum more relevant and interesting and at the same time enhance literacy skills with the pupil producing a piece of extended writing.

However it is redesigned, it is of primary importance that assessment reflects, and encourages engagement with, the full range of desired skills, knowledge and understanding being developed in the course. The fact that it is more challenging to assess these broader thrusts should not be allowed to get in the way. Whilst suggesting that alternative in-course assessment exercises might play a useful role in producing better balanced assessment, we would also stress that any such moves should not run counter to addressing over-assessment. Many in higher education believe that their own assessment regimes have sometimes become over-burdensome, and that one factor which has driven this has been the growing reluctance of entrants to exert effort on any aspect of a course where its direct relevance to assessment credit is not immediately and directly obvious.

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[35] Evidenced for instance in discussions at the Education Committee of the Scottish Parliament (June 2004), available at http://www.scottish.parliament.uk/business/committees/education/or-04/ed04-1602.htm

[36] Report of the Curriculum Review Group, November 2004, SEED, available at http://www.scotland.gov.uk/library5/education/cerv.pdf

In England, the Working Group on 14-19 Reform[37] states that "assessment (*of the diploma)* must consolidate learning, extend understanding and develop skills, as well as measure achievement". They have work under way to develop an assessment regime which

- enriches the learner's experience by using a variety of types of assessment;
- ensures that all assessment is fit for purpose;
- avoids placing an undue burden on learners and teachers;
- embraces the potential benefits of e-assessment;
- makes appropriate use of the professional judgement of teachers; and
- is reliable and quality assured.

This seems a sound approach to assessment design.

Additional help may come from the Assessment Reform Group which has published a leaflet on the ten principles of Assessment for Learning. Major advances appear to have been made by using formative assessment in making pupils more eager to learn and in helping teachers to address identified difficulties. Scotland's project *Assessment is for Learning*, managed by Learning and Teaching Scotland[38], has been involved in evaluation of a project using this approach. Aims of the evaluation were to find the extent to which the project improved pupil-learning, motivation and improved pupil attainment. The final report was produced in August [39] and the feedback is positive.

Schools adopted a wide range of formative assessment strategies across a range of subject areas. These included the development of higher order questioning techniques such as: the promotion of thinking skills; the use of problem solving techniques; traffic lighting; group and pair work; discussions; feedback comments rather than grades; oral feedback from teachers; sharing assessment criteria; peer assessment; redrafting of work; developing communication skills and adopting more inclusive pedagogical strategies.

There was a substantial increase in perceptions of pupils' engagement with learning. The impact on lower attainers, shy, and disengaged pupils was particularly notable. Pupils were better motivated and demonstrated more positive attitudes towards learning. Many were more confident.

Generally, participating pupils were already well behaved, but there were reports of improvement for some pupils and improved classroom ethos with a focus on cooperation, team work and learning.

There were dramatic improvements in pupils' learning skills. They learned about their own learning, their strengths and weaknesses and what they needed to do to make progress. This encouraged them to take more responsibility for their learning.

Pupils' evaluations were generally positive, although some of the higher attaining pupils reported boredom with the slower pace, while other pupils, particularly at secondary level reported embarrassment at having to publicly answer questions and indicate their level of understanding.

The project generally had a positive effect on the performance of participating classes. The project was perceived to have been successful in improving pupil learning and motivation (89%), the quality of students' work (88%), attainment (78%), learning skills (94%) concentration (83%) and behaviour (55%). Concerns were however raised about the tensions between implementing formative assessment strategies and preparing pupils for summative assessments. More time was taken to cover the curriculum using this approach and so content may need to be reduced if this method of teaching is to be introduced.

This Assessment is for Learning Project fits in well with the purposes of the Curriculum for Excellence and the thrust towards less cluttered courses. Most of the research has centred on primary schools and at the S1 and S2 stage in secondary school. It would be of interest to investigate the effect that formative assessment would have on pupils in S3-S6.

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[37] Working Group on 14 – 19 Reform, Interim Report, DFES (April 2004) [available through 14-19reform@dfes.gsi.gov.uk

[38] http://www.ltscotland.org.uk/assess/about/evaluation/index.asp

[39] http://www.scotland.gov.uk/library5/education/ep1aldps.pdf

We were delighted to discover that the Scottish Curriculum Review Group's Report, *"A Curriculum for Excellence"* proclaims future general principles absolutely in accord with our own wishes. It argues that the curriculum should:

- make learning active, challenging and enjoyable;
- not be too fragmented or over-crowded with content;
- connect the various stages of learning from 3 – 18;
- encourage the development of high levels of accomplishment and intellectual skill;
- include a wide range of experiences and achieve a suitable blend of what has traditionally been seen as 'academic' and 'vocational';
- give opportunities for children to make appropriate choices to meet their individual interests and needs, whilst ensuring that these choices lead to successful outcomes and
- ensure that assessment supports learning.

The point on assessment is listed last, but we feel it is expressed in exactly the right terms. We would assert that, in order to accomplish the visionary aims of the preceding six points, it is critical.

6.i. International Assessment And Surveys: PISA 2000, TIMSS, AAP and ROSE

International surveys and comparisons seem to show that many of the issues raised during our project are shared widely internationally. We have learned a little about curriculum discussions and developments in other parts of the world, but have not studied the range of initiatives deeply or widely enough to justify presenting out own analysis or critique. We do believe that, in proceeding with a detailed science curriculum review, it would be useful to survey the significant activity being taken forward elsewhere. We do not believe, however, that there is an "off the peg" model solution already available elsewhere.

On the other hand we feel it worth noting that international surveys which assess groups of pupils in a large number of countries give mixed messages about Scotland's relative standing. We also draw attention to the ROSE project, an international initiative to gauge pupils' interests in different aspects of or approaches to science, and we suggest that it might be useful for Scotland to take advantage of this.

In 2003 Scotland took part in two international student assessment programmes. The Trends in International Mathematics and Science Study (TIMSS) assessed mathematics and science achievement among a sample of pupils aged 9 and 13 in over 50 countries. The Programme for International Student Assessment (PISA) is run by OECD (Organisation for Economic Co-operation and Development) and samples 15 year olds for mathematical, reading and scientific literacy and also problem solving ability. In 2003 the main aim emphasis was on mathematical literacy. The results of these surveys were published in December 2004.

PISA 2000 assessed students' capacities to apply knowledge and skills in reading, mathematics and science. Scotland performed well in this survey, coming 6th in reading literacy, 5th in mathematical literacy but only 9th in scientific literacy from about thirty countries. The results of the 2003 survey were broadly similar to the 2000 survey.

TIMSS carried out a survey in 1995 and Scotland was one of the countries taking part. At Primary 4 and Primary 5 pupils were 15th out of 24 in mathematics and 12th out of 24 in science. Results from this survey for S1 and S2 pupils showed Scotland at 27th out of 40 for mathematics and 25th out of 40 for science. At S1 and S2 their counterparts in England (10th in science) and in Ireland significantly outperformed Scottish pupils.

The results of the 2003 survey have now been published and results are broadly similar. At S1/S2 Scotland was 18th for mathematics and 18th for science out of about 44 countries. The Far-Eastern countries, some Eastern European countries, Russia, the USA and Australia all performed significantly better. At the primary 5 stage only 25 countries participated and here Scotland's mathematics achievement results were below the international average, again in 18th position. England performed significantly better at 10th position and above the international average. The science results at this stage show Scotland in 16th position with a score above the average mark and with England being in fifth position. The TIMSS report suggests that our pupils are not being stretched enough in mathematics, neither in primary school nor in the S1 and S2 years. This is also the impression gained from discussions with the university community.

The Assessment of Achievement Programme's sixth Survey of Science 2003 tested knowledge and understanding of science for the first time and showed that fewer than 10% of the P7 and S2 pupils were secure (scored 65% or over of the marks for the tasks set) at the target levels for these stages, i.e. Level D for P7, Level E for S2. 75%-80% failed to show evidence of basic attainment (scored 50% or over) at these levels.

6.ii. The ROSE (Relevance of Science Education) Survey

This is quite different to the PISA and TIMMS surveys as it is designed to test attitudes rather than scientific knowledge. This is an international comparative project designed to shed light on what is important to the learning of science and technology (S & T) as perceived by the learner. Lack of relevance of the S& T curriculum is thought to be one of the greatest barriers for learning as well as interest in the subject. The ROSE project hopes to provide the theoretical insight into the relevance of the contents as well as the contexts of the S&T curricula. The key feature of ROSE is to gather and analyse information from factors that have a bearing on the students motivation to learn S&T.

This survey would provide a useful tool to those involved in curriculum design. It appears that attitudes to science alter with gender and nationality and so each country needs to carry out its own survey. Scotland did not participate at the initial stages of this project but could still use the questionnaire.

The results of the TIMSS 2003, PISA 2003 and the AAP's Survey of Science should be studied and taken into account in any review of mathematics and science courses. However, the ROSE survey is the only survey which gives information on pupils' attitudes and interests in science and so this could prove instrumental in "switching pupils on to science". We strongly recommend that such a survey is carried out.

7. School Leaving Qualifications As A Predictor Of Class Of Degree Awarded

A survey[40] had been carried out previously at the University of Glasgow on the correlation of examination performance in an introductory chemistry course with students' entry qualifications. For a period of two years only a very weak correlation was found. However, for the next three years there did appear to be a much more significant level of correlation. The reason for these results was believed to be that in the first two years a series of pre-lectures were delivered to help bring students with poorer qualifications up-to –speed, whereas in the latter years this practice had ceased. This indicates that university entrants with relatively poorer school grades can cope well if they are sufficiently motivated and are provided with appropriate support.

To investigate the relationship between school leaving qualifications and final class of degree awarded we examined the 2004 Science and Engineering graduate data from the Universities of Glasgow and Paisley. We also looked at a recent set of data from the first year chemistry course at Glasgow. At present we are working on the statistical data obtained and hope to produce a separate and more quantitative report at a later date. However on looking at the data we can draw preliminary conclusions which we give below.

A survey, using the grade of pass of Higher, Advanced Higher and A Level Chemistry against the mark obtained at the end of the first year chemistry class, has been carried out [41].

[40] G Sirhan, C Gray, A Johnstone and N Reid, Preparing the Mind of the Learner, University Chemistry Education, 1999, 3 (2)
[41] See Appendix J, Tables 9(a)-((d)

There is a fairly good correlation, on average[42], between the mark obtained in the end of year exam and the grade of entrance qualification. Generally, the better the Grade the higher the End of Term mark. This, however, does not tell the complete story and many students with a B Higher gain as high marks as those with a Higher at A and there are several with A grade passes who fail the first year chemistry exam.

On studying the results[43] for the classification of Engineering Faculty degrees obtained at the University of Paisley with the points score of the Highers gained at school it was found that significant numbers of students obtained First Class Honours degrees with comparatively poor entry qualifications (less than 10 points), so comparatively poor entry qualifications are no barrier to obtaining a good degree. Similar, although not so marked, results were obtained from the University of Glasgow[44].

On looking at how good Higher Mathematics[45] is as a predictor of success in Mathematics based Science and Engineering degrees it was found that the better the Higher Grade in Mathematics the more likely the chances of obtaining a good degree.

We regard these analyses as significant. They confirm a pattern that we believe has been reported in studies in England from many years ago. In general, the grades recorded at school are often poor predictors of relative success at university. Many other factors can have influence, and almost every lecturer has anecdotal recollections of particular, very unpromising, students who unexpectedly "took off" academically part way through their degree studies, with spectacularly successful consequences. Where a course is over-subscribed with applicants, universities must apply some objective criteria to decide on whom to admit, and entry grades are widely regarded as the fairest and best predictor available. From the point of view of this project, however, we can first conclude that there seems to be no grounds for universities to regard the current school assessment regime as "tablets of stone" that in detail give them precisely reliable information about the relative prospects of different applicants. Our consultations indicate that universities are relaxed about potential significant changes in the school assessment regime. If changes in school assessment help in promoting improved pupil attitudes, skills and broader understanding, as argued for in this Report and in "A Curriculum for Excellence" document, then universities could not only be relaxed but also excited.

8. Report of the 3-18 Curriculum Review Group: an Enthusiastic Response

Three quarters of the way through our project, as our conclusions were hardening and the broad consensus amongst our participants had become confirmed, the Report of the Scottish Executive 3-18 Curriculum Review Group was published. We found it exhilarating to discover how closely the vision of the Review Group's statement: *"A Curriculum for Excellence,"* drawn over a much broader canvas than our own STEM-focussed review, was nonetheless expressed in terms which had such strong convergence and synergy with our own conclusions.

From our perspective it was even more encouraging that the Minister announced that Science should be taken as the first subject area to be reviewed in the context of the new vision. We are immensely grateful that this is to be the case, and we think that this provides an important and timely opportunity. We feel that, in the fast-moving STEM area, the coherent university network we have identified could make a significant contribution to the review, by helping design and delivery of development support for the teaching community. Any such contributions must, we clearly recognise, be in a supporting role.

[42] See Appendix J, Diagram 1 on p44, Breakdown of GU Students' 1st Year Exam marks by Higher Grade in Chemistry.
[43] See Appendix J, Table 11 and the diagram on p44, UoP Engineering Bachelors Graduates.
[44] See Appendix J, Tables 11 and 12 and diagrams on p44 labelled GU.
[45] See Appendix J, p44 the two diagrams at the foot of the page.

In this section we review the extent to which our conclusions cohere with the wider vision of the *"Curriculum for Excellence,"* and this leads to some tentative conclusions about how we might contribute towards taking things forward.

Match of our own recommendations to the drivers of the *Curriculum for Excellence*

The outcomes, purposes[46] and principles espoused in "A Curriculum for Excellence" are consistent, in almost every element, with the thrust of our own analysis and recommendations in the context of the sciences. Indeed we believe that the sciences, suitably (and radically) remodelled, provide very fertile territory for taking forward the broader educational agenda.

The six outcomes sought by Ministers in their foreword to the *Curriculum for Excellence* document are highlighted below in italics.

- *"for the first time ever, a single curriculum 3-18, supported by a simple and effective structure of assessment and qualifications: this will allow the right pace and challenge for young people, particularly at critical points like the move from nursery to primary and from primary to secondary"*

  – *a single curriculum*: we argue for coherence with reference to a clearly identified set of "major ideas" with steady progression in depth and sophistication; the *critical points* we wish to see smoothed are those between primary and secondary and from "5-14" to Standard Grade

  – *a simple and effective structure of assessment and qualifications*: we recognise this as of critical importance and would do all we can to ensure that universities provide encouragement and no obstacles to a radical review

  – *the right pace and challenge for young people:* we believe this is very important and link it to our comment on the next targeted outcome

- *"greater choice and opportunity, earlier, for young people, to help them realise their individual talents and to help close the opportunity gap by better engaging those who currently switch off from formal education too young"*

  – whilst we have not expanded at length on the issue of addressing the needs of groups of different abilities and engagement (at any given stage), we do believe there is great scope for this in addressing "real" and recognisably relevant applications, illustrations, investigations, and practicals, and tuning these differently for more academically and more craft-oriented groups: science and technology provide rich opportunities for stretching the most talented and engaging the interest of all

  – *those who currently switch off:* science has a well-demonstrated capability to SWITCH ON pupils; the work of science centres and other 'road show' providers demonstrates this, and some consideration might be merited into how larger and useful educational experiences could be built around such inputs; pupil centred approaches are known to be likely to increase the likelihood of achieving engagement and projects of various scales and outlook could have a part to play in attracting engagement

- *"more skills-for-work options for young people, robustly assessed and helping them to progress into further qualifications or work"*

  – this is not an area we have discussed in any detail, but we are in sympathy with it; it is one of our themes to connect science to real life application and we

[46] To see the purposes of the "A Curriculum for Excellence" see Appendix K

would hope that a fair percentage of skills-for-work experience would have a STEM basis

- we are also anxious to see an in-depth analysis of the academic, vocational and practical spectra: this is not a one-dimensional matter as, for instance, engineering and medicine are both academic and vocational, and space science is both "blue skies" and dependent on technological ingenuity and extremely developed craft skills: we believe that all pupils should experience something of this range

- *"more space in the curriculum for work in depth, and to ensure that young people develop the literacy, numeracy and other essential skills and knowledge they will need for life and work"*
  - we advocate that the present courses are "decluttered" to enable more in-depth studies
  - we are also keen to see opportunities for numeracy and literacy to be more developed within the science curriculum to reinforce key skills introduced in mathematics and English
  - we recommend that more extended problem solving exercises are set which will involve calculations and the writing of reports
  - problem solving exercises should importantly include planning and performing experiments, collecting and assessing results, and then presenting these clearly
  - in studies of applications and issues, information could be collected from a range of sources, including the internet, and then organised, debated and presented

- *"young people achieving the broad outcomes that we look for from school education, both through subject teaching and more cross-subject activity"*
  - we advocate that the general skills of numeracy, literacy and problem solving should be improved throughout the STEM subjects in school
  - we also recommend more cross-subject activity, both between the sciences and between science and other subjects. This could involve simple collaboration between teachers of different subjects to the production of a significant report by the pupil on a given topic that would cover several subject boundaries (This is detailed below under 'Project work')

- *"more space for sport, music, dance, drama, art, learning about health, sustainable development and enterprise, and other activities that broaden the life experiences - and life chances - of young people"*
  - *learning about health and sustainable development*: these are both topics that could be covered in a Science in Society type of course
  - *other activities that broaden the life experiences - and life chances - of young people:* we have recommended that science teaching could be greatly enriched by broadening the science experience of pupils with field trips, industrial visits and visits to exhibitions and science centres.

In the Ministerial Response to "A Curriculum for Excellence" science has been chosen as the first area to be reviewed. The review states that:

"A cycle of continuous updating and reform of the curriculum across all areas of learning will begin immediately, starting with the science curriculum 3-18."

It goes on to state that:

"the current science curriculum needs to be updated, expanded and improved. All of the existing science curriculum will be assessed against the principles and purposes of "*A Curriculum for Excellence"*, and the recommendations of earlier and current reviews of science education will be addressed. Unnecessary or outdated content will be removed, gaps will be identified and be filled, content will be updated and progression between stages and courses will be smoothed out."

- we advocate a decluttering of the science curriculum and are keen to see a more smooth transition between the different stages and courses and have gone so far as to look at areas where the current Highers could be pruned. We would however argue that this "cut and paste" type of approach will not achieve the type of curriculum that is required for all our young people in the 21st century.
- the science curriculum needs to contain a clear statement of its aims, stating why the study of science is valuable for all school pupils and also what we would want them to gain from the curriculum, before any attempt at design can begin.

  From our project we have found that the curriculum needs to cover at least two strands, one for the future scientist and the other for the responsible citizen.

It is not the purpose of this report to identify these aims but we can perhaps look at what can be gleaned from the *purposes and principles* of the Review (see Appendix K).

One of the purposes of the Review is that every young person should be a <u>responsible citizen</u> able to "evaluate environmental, scientific and technological issues" and also to "develop informed ethical views of complex issues".

- a "Science in Society" type of course should be designed for all pupils as a core component of any science course to meet this purpose. Within such a course other aims of the <u>successful learner</u> who will have "an openness to new thinking and ideas and similarly the <u>confident individual</u> will have the ability to "assess risk and take informed decisions" should be achieved.

<u>Successful learners</u> will be able to: use literacy communication and numeracy skills; use technology for learning; think creatively and independently; learn independently and as part of a group; make reasoned evaluations and link and apply different kinds of learning in new situations. <u>Effective contributors</u> will be able to: communicate in different ways and in different settings; work in partnership and in teams; take the initiative and lead; apply critical thinking in new contexts and create and develop and solve problems.

- These two capacities could be developed within a science curriculum. We advocate a reinforcement of core skills within the sciences. Again the completion of a project would further hone these skills.

Let us now look at the seven principles for curriculum design:

Challenges and enjoyment:

- We are delighted that this has been given a high priority as we need to encourage our young people to be interested in science and engineering.
- A range of science courses will need to be designed to engage and motivate the pupil. A ROSE survey and a study of different curricula from across the world may provide ways towards producing such courses.
- Constructing a curriculum in a slightly different way using a themed or applications led approach should also be investigated.
- A "Science in Society" type of course has been shown to motivate pupils and the need for such a course has already been identified.
- The introduction of more practical work should also be considered.

- Pupils should be more involved in their learning and the results from the Assessment is for Learning pilot should be investigated with a view to expanding it to other courses and to a different age range.

Breadth, progression, depth and choice:

- Pupils should be able to select from a broad range of courses and should be able to progress within a subject and also to increase the breadth of their experience by taking clusters of similar subjects. Courses should be designed for those wishing to follow an academic route and also for those who wish to adopt a more "hands on" approach.
- We have argued previously that courses should be decluttered to allow a few topics to be covered in more depth.
- Choice should be available in the science subjects. In addition to Science in Society there should run in parallel science courses up to Higher which cover biology, chemistry and physics. At Advanced Higher individual science courses would be available.

Coherence and relevance:

- Again this is something that we wish to encourage. Clear links between different subjects should be made
- Pupils achieve more when they are actively engaged in the learning process and they see the relevance of what they are learning.

Project work

The purposes of "A Curriculum for Excellence" could be met with the introduction of a multidisciplinary project. Work could be carried out on a cross curricular project involving a scientific issue where pupils are required to work individually and as part of a group. This extended project could be used to support the purposes of the 3-18 curriculum particularly the following listed under "and able to":

- *Develop and communicate their own beliefs and views of the world*
- *Assess risk and take informed decisions*
- *Evaluate environmental, scientific and technological issues*
- *Develop informed, ethical views of complex issues*
- *Communicate in different ways and in different settings*
- *Work in partnership and in teams*
- *Apply critical thinking in new contexts*
- *Create and develop*
- *Solve problems*

There are many examples of materials for extended projects and how to organise them on the web. Some examples of extended projects are given below:

1. *The effects of climate change across Scotland.*

Cross links: Biology, chemistry, physics, geography, modern studies, managing environmental resources, politics.

Source of material: The Heat is up and it's raining. Educational pack, Advances series No.7 *SNH.* http://www.snh.org.uk/pdfs/publications/education/advances/TheHeat.pdf

2. *Choice of Refrigerants and their effect on the Environment.*

The aim of this project is to introduce the gas laws, basic thermodynamics, free radicals and the ozone layer as well as finding out how fridges work and the refrigerants commonly used.

Cross links: chemisty, physics, biology and geography.

3. *Forensic Investigations*

There are various forensic investigations obtainable at: http://www.courttv.com/forensics_curriculum These give a mystery synopsis, followed by classroom experiments which will give clues as to who the culprit was. Some of the tests are fairly standard but others involve things such as hair and fingerprint identification, which should develop observational skills and deductive powers. The investigations are developed in partnership with the American Academy of Forensic Sciences and the National Science Teachers Association and are obviously designed to try to motivate and enthuse school pupils to study science. There are currently six of these investigations on the web and they are designed for secondary school pupils.

9. The Way Forward

The conclusions of this university-based project on STEM subjects align astonishingly well with the general values, purposes and principles espoused for "*A Curriculum for Excellence*" and also with the more specific science issues identified in the Ministerial Response. It is of national importance to review the science curriculum urgently, though we recognise this will be a major task and will take significant time to work through and to implement. And science moves on so quickly that mechanisms will need to be revised to accommodate ongoing incremental change in some of the topics covered or their supporting materials.

Immediately following the publication of the national *"Curriculum for Excellence"* Report we were invited to meet members of the Executive Committee of the Association for Science Education Scotland. We discovered that we shared very similar views, not only on the broader issues where we both were delighted with the Scottish Executive's general statement, but also in our ideas about specific approaches which could transform science education. We very quickly began to consider how we might be able to contribute collaboratively to help in the process of achieving a successful review of the science curriculum. The ASE brings together committed, experienced and imaginative teachers, very well placed to judge what is practical to deliver in schools for pupils progressing in age and differing in ability. The university network of academics, enlisted during our own project, encompass a vast range of knowledge and understanding of science. If the school curriculum is changed in the significant ways we (and the ASE) suggest then this will introduce topics and applications which are outside the experience of currently practising teachers. University advice could support a careful analysis of various approaches and topics that might be considered. We reiterate here that we readily recognise that universities should not dictate detailed arrangements for a new curriculum, but they can provide useful and supportive advice. University involvement can in the end significantly strengthen confidence in the robustness of the outcome. Beyond this, universities could cooperatively design and deliver relevant CPD courses for teachers, and contribute to the development of suitable support teacher materials. For a more relevant curriculum, support materials will require periodic review and CPD will indeed need to be 'continuing.' Hence we believe it could be of long term value if we could be actively involved, alongside the ASE, in the Review process. In addition to supporting and informing the immediate Review itself, we could aim to establish a framework that could support the delivery and evolution of school science education into the future.

We recognise that important sectors of industry and relevant professional bodies are very important stakeholders, heavily dependent on successful education in STEM subjects, and our Project Advisory Group encouraged us to discuss our conclusions at an early stage with a representative group representing professional bodies and significant companies in Scotland. We held such a small exploratory meeting on 15 February 2005 with a group of 14 individuals representing a wide range of sectors[47], with the Chair of ASE Scotland also presenting. Short presentations outlined the thrusts of the *"Curriculum for Excellence"* statement, our project conclusions, and the stance of the ASE. Those present were keen to attempt to involve an industry voice also in an alliance to support a positive review process for school education in science, and across the wider STEM agenda.

We look forward to the Science Review process, and its implementation. We would hope that arrangements could be made that would enable us to contribute actively and constructively. We would be enthusiastic in this regard to work in close collaboration with the ASE in Scotland, and to help marshal positive and coherent support from industry and professional bodies.

[47] Organisations represented were the Bioindustries Association, IMechE, RSC, SCI, Scottish Enterprise (Chemicals & Life Sciences), Scottish Engineering and SEMTA. Companies represented were BAE Systems, Glaxo SmithKline, Intense Photonics and Organon