Connecting it up: Towards a Route Map for STEM education in Scotland

A STEM-ED Scotland collaborative project with the Association for Science Education (ASE), the Scottish Mathematical Council (SMC) and the Scottish Technology Teachers Association (STTA) funded by the Esmée Fairbairn Foundation

Project Summary Report December 2011

1. Background

The Esmée Fairbairn Foundation funded this project from its *New Approaches to Learning Fund*, supporting work undertaken during the period from April 2010 till December 2011. The Scottish Government provided supplementary support, funding the equivalent of three months of this period, for related work which is integrated within this report. Dr Elsa Ekevall was employed as the project coordinator and researcher, and she led and undertook almost all of the research, analysis and drafting work involved, though always in active consultation with the project Steering Committee and with numerous groups of teachers. Part-time administrative support was provided by Jennifer Kirk. The project Steering Committee members were:

John Coggins, Moira Finlayson and Alan Roach, representing STEM-ED Scotland
Stuart Farmer, representing ASE Scotland
Chris Pritchard (till Sept 2010) and Eddie Mullan (subsequently) representing SMC
Gordon Greig, representing STTA

Taking advantage of the new and rather flexible curriculum guidance for 3-15 year-olds in Scotland, the key purpose of the project was to illuminate how to design a modernised and coherent curriculum progression plan, in order to enhance conceptual understanding and skills development across science, technology, engineering and mathematics disciplines (STEM). Importantly, the project also aimed to seed a process of implementation for such a structure, highlighting the considerable range for flexibility in the choice of topics and contexts allowed by the curriculum guidance in Scotland.

In essence the project aimed to provide arguably the first model that translates modern post-school reappraisals of the challenges of "STEM education" into a coherent route map for the first 10 years of schooling. The traditional disciplines are still recognised, but the complex web of ideas and skills that interconnects them has been directly addressed in a number of areas.

A brief review of the project is given in Section 2 below, followed in Section 3 by a statement of the project conclusions. Section 4 gives a more detailed review of the project's work and process. The main detailed outcomes of the project are presented in other more specific documents. A composite guide to accessing these is given in Section 5: Links to Project Outputs.

2. Project Summary

The project involved a great deal of dialogue with practising teachers, most of whom were initially contacted through the ASE, the SMC or the STTA. The interaction process included an initial

survey, a stakeholder meeting, three development events, a number of focus group discussions of draft documents, and a variety of other meetings. These are described in a little more detail in Section 4 below, which incorporates reference links to fuller descriptions in the form of meeting reports and project newsletters.

Following an initial review of international research relevant to the project's aims, we settled on an approach which involved articulation of *Learning Pathways,* to be developed for a number of important conceptual themes where learners face a journey from initial introduction towards an ever deepening understanding. There is growing interest in this kind of approach in the USA, where a number of groups have drafted, and are testing, pathway guidance for individual themes. We have developed this approach using a much more broadly based dialogue with teachers, and we believe we have developed a larger set of *Pathways*, based on a common approach, than has previously been attempted. We have also connected this in some great detail to the new Scottish *Curriculum for Excellence* (*CfE*) model. Curriculum guidance for the 3 – 15 age range, is expressed in terms of a number of quite generally expressed "*Experiences and Outcomes"* that all learners should address[1]. This approach provides great flexibility and scope for initiative in terms of ***how*** these are addressed by individual teachers and schools. This is a most welcome feature that should encourage an education process which is much more engaging and learner-centred than has been the norm in the past. However, concept development and "big ideas" are not explicitly referenced in the guidance. *Learning Pathways* will map how these can be progressively developed, though in the Scottish curriculum model, it is important to highlight the wide range of flexibility there can be in the choice of contexts through which they are addressed.

Five Learning Pathways have been developed and documented, covering:

- Models in STEM
- Genetics & Inheritance
- Measurement, Units & Scale
- Mechanical Systems
- Energy

The **principal documented outputs of the project** consist of the paperwork describing each of these *Pathways* together with the **Project Conclusions** paper, drawn from the discussions at the End of Project Review Event, held in October 2011. Links to electronic versions of these documents are provided in Section 5 of this Report.

The Project Conclusions provide guidance on how the Pathways documentation can most effectively be used, and suggests that teacher groups should adopt these as starting versions for their own working documentation, adapting them to their own more detailed and specific curriculum planning. A large proportion of those who took part in the End of Project Review Event expressed interest in being involved in further work towards application of one or more of the pathways.

The Conclusions are summarised in the following Section

[1] *Experiences and Outcomes* are set out for a number of broad curriculum areas, including Sciences, Technologies and Numeracy & Mathematics. They are expressed over five levels, running over education from Nursery till the 3rd year of Secondary School. See:
http://www.ltscotland.org.uk/understandingthecurriculum/whatiscurriculumforexcellence/
http://www.ltscotland.org.uk/myexperiencesandoutcomes/

3. Project Conclusions

3.1 The learning pathways approach

The pathways in general analyse how understanding of a particular "big idea" in science, or a "key practice or skill" can be built through the educational process, progressing over the years of schooling, with clear linking and reinforcement across the STEM disciplines. A learning pathway does not necessarily map the precise journey through which each and every learner's personal thinking and understanding evolves, but it does usefully help to guide teaching strategies at successive stages, which can be geared to build steadily more sophisticated levels of understanding among learners.

3.2 The pathways developed

The five different pathways developed span a range of different types of challenge:

Modelling is an approach universally characteristic of science and technology, yet one which is often employed almost subconsciously, without explicit attention to how well or imperfectly the model used fits with the more complex reality which it provides a prop for understanding.

Measurement, Units & Scale involves mathematically rooted understanding and judgement that is of critical importance for all STEM subjects. This area is in general poorly developed in school education, a situation that could be transformed by following a coherent cross-disciplinary approach.

Genetics & Inheritance is a fast developing area, involving a long ladder in core concept development, and interacting with progressively deeper understanding of other key ideas of science and mathematics.

Mechanical Systems represents a key and progressive developing theme in technology and engineering with embedded cross-disciplinary links, especially to physics.

Dealing with Energy, in a vastly diverse range of contexts, is a well-recognised educational challenge, where different terminologies and different points of view are commonly taken in different scientific and technological contexts, and indeed in everyday life as reflected in the media.

The pathway documentation for each of these five concept areas reflects their diverse characteristics, albeit that all were developed by applying the same principles of analysis.

3.3 The pathways documentation

A general conclusion was reached that whilst the documents have a number of very useful features and identify progression and cross connections in concept development, they will be unlikely to make much impact on classroom practice if they are left simply as a set of available stand-alone publications. The documents can be used as a starting point for developing very useful teacher CPD (see 3.8 below) and as an initial guide to be adapted by groups of teachers planning productive routes through the curriculum. Adaptation of the documents for primary teachers would in most areas be advisable, both for CPD development and for use by teacher groups.. There was general agreement that the documents have very valuable features in that they:

- map the contributing and interacting strands in concept development
- identify rich links to the *Experiences & Outcomes* curriculum guidance
- draw attention to common misconceptions
- provide useful glossaries of terms

3.4 The concept development diagrams

The general view was that some caution needs to be exercised in presenting these. There are concerns that the complexity of the diagrams (in some cases) may be found somewhat perplexing and perhaps off-putting by many teachers, on first exposure. This view was tempered by recognition that the concept development challenge itself is inherently complicated, and that the diagrams do expose the connections that need to be made to address these issues. It was also argued that the diagrams usefully identify a very rich range of *Experiences & Outcomes*, where opportunities could be taken to build and enrich understanding of important concepts. . As one Review Event participant put it, the diagrams are very useful to "see the big picture," and to clarify "where you've come from and where you are going." The issue perhaps comes down to giving careful consideration to how the diagrams are formatted (or reformatted by groups of teachers) for a given purpose

3.5 Misconceptions

The highlighting of common misconceptions at each stage for a given concept area was very widely welcomed. Perhaps one key benefit of focusing on core conceptual development, whilst dealing with the relatively disparate range of topics pinned to *Experiences & Outcomes*, might encourage explicit class discussions of the concepts, flushing out and remedying misunderstandings. The lists of misconceptions given in the pathway documents will usefully be refined and extended by teacher groups discussing or adapting the documents.

3.6 Links to *Experiences & Outcomes* and cross-disciplinary connections

The general welcome for this feature, and for the fullness and richness of the lists of links provided, has already been noted in 3.4 above. How this information is formatted might need to be reconsidered if it is decided radically to simplify the way that the concept development diagrams are presented.

3.7 "Implementation"

One participant at the Review Event commented: "I think this is an erroneous concept – these pathways are not to be followed in this sense, but they ought to help forward planning and teacher – teacher dialogue." Several others happily expressed interest in being involved in "implementation" of one or more pathways. The divergence between these reactions is probably much less significant than might appear at first sight: using, and adapting, the pathways materials as a guide in group discussions on coherent curriculum planning amounts to "implementation" of the ideas inspiring the "Connecting It Up" project. There was strong support for using the documentation to develop a useful CPD model through which such "implementation" would be progressed (see 3.8 below). This might prove to be the main transmission mechanism though it may not be the only one

3.8 A **framework for "professional conversations" and teacher CPD**

The majority of teachers do not in practice involve themselves in out-of-school subject related CPD. Also, release to attend such CPD, at least within formal working time, is becoming increasingly difficult to arrange. It was persuasively argued that the learning pathways could be made the basis for a key advance, which would encourage within-school "professional conversations" among staff across the different STEM disciplines. Such a group was described as a "Teaching & Learning Community" led by a volunteer coordinator. A first objective would be to offer to "train these trainers." It was stressed by a number of participants that it would be vital to recruit active support for such initiatives at Head Teacher and Local Authority levels.

3.9 **Role for a universally accessible website**

It was thought that it would be very helpful to have "a universally accessible website," easily, and freely open for individuals and groups of teachers to publicise and communicate about their curriculum planning initiatives. Possibilities on this front will require some exploration.

3.10 A **model to promote and to celebrate best practice**

The operational model of the Optoelectronics College[2] was strongly recommended for its good website, for its use of membership certificates and badges, and for supporting kite-marks.

3.11 **Scope for development of further learning pathways**

It was recognised that the pathways developed through this project represent a small subset of STEM concept areas. There were indications of strong support to develop as a priority one or more pathways dealing with use of symbols, algebra, notation and graphs.

4. Summary of the Work and Process of the Project

This Section gives an account of the work carried out during the project, reviewing how the Learning Pathways were developed and evolved, and the consultation and dissemination processes undertaken.

4.1 Initial review and preparation

A number of useful resources and examples of good practice regarding learning progressions, dealing with misconceptions, integrating the curriculum, and skills in STEM were identified.

The majority of previous work on learning progressions has been in the USA and mainly in the science field. A number of researchers have looked at various areas including: particle model of matter, atomic theory, force and motion, chemical reactions, evolution and modelling and curriculum focal points for coherence in mathematics from prekindergarten

[2] The Optoelectronics College is an innovative project to support the classroom teaching of Optoelectronics in secondary school science to pupils in the 11-13 age range. See http://www.opto.org.uk/

through to grade 8. Similarly most of the previous research identified on Interdisciplinary or Integrated Learning are from the USA.

It was noted that Learning &Teaching Scotland had identified two broad types of interdisciplinary learning[3], documented as appropriate to the new *Curriculum for Excellence* in Scotland. The development and use of STEM Learning Pathways through this project should contribute to planning activities for both of these strands.

More details on the research review findings can be found in the reference links WP2 and WP4 in Section 5 below.

4.2 Online survey of practitioner views

An online survey was developed, and used to inform the core areas for the development of the first STEM Pathways and to identify people interested and experienced in learning progressions and dealing with misconceptions. The survey asked participants for their views on core areas in STEM that should be prioritised in the development of Learning Pathways or areas where pupils form mistaken beliefs or have difficulty in understanding.

They were also invited to share personal experiences of learning progressions, dealing with misconceptions and linking the STEM areas. The survey was available from mid June 2010, and (in acknowledgement of the distractions of the school s' session end, summer vacation and new session start) remained open till October. The access details for the survey were distributed to potential participants through email distribution lists and a number of other routes, including through advisers in Education Authorities and the three organisations involved in the project. There was a healthy response, with a total of 121 individual returns from a range of organisations. Participants were invited to complete only sections that were relevant to them. 52 completed more than one section.

There was a high degree of interest in ***taking part in the development of the STEM Pathways*** (n=20) and in an ***Advisory Forum*** (n=27). The main uses of the STEM Pathways were believed to be: to make connections to other subjects, to progress learning, and to teach core concepts. No areas for exclusion were identified by the survey. The respondents drew attention to a number of areas to prioritise in the development of the learning progressions, with the most frequently mentioned in each subject:

mathematics - length, weight and volume
science - renewable and non-renewable energy sources
technology - food health and safety.

A number of areas were identified where misconceptions are common, the most frequently mentioned in each subject were:

mathematics - fractions, rounding, estimating, ratios, proportion and percentages
science - weight and mass
technology - selection of materials.

The skills that the respondents regarded as the highest priority in the development of the learning progressions were: making observations, raising questions & formulating hypotheses, written & oral communication and interpreting results.

[3] Learning & Teaching Scotland (now part of Education Scotland) is the principal curriculum body for Scotland seeks to develop awareness and understanding of the connections and differences among subject areas and disciplines. (2) Using knowledge/learning from different disciplines to explore a theme or issue, meet a challenge, and solve a problem. www.ltscotland.org.uk/Images/InterdisciplinaryLearning_tcm4-620626.pdf

The full analysis of the survey results is referenced through link WP3 in Section 5 below.

4.3 Stakeholder Forum

On 31 August 2010 a meeting was held for major stakeholders under the title "*Linking Science, Technology, Engineering and Mathematics through STEM Pathways."* Discussion focused on the aims of the project and on effective ways of taking the work forward in line with Curriculum for Excellence.

Members of the project team made brief presentations on

(a) the project and development of STEM Learning Pathways
(b) current research into learning progressions and concept development
(c) making connections across the STEM subjects, providing opportunities for deepening learning and reinforcing concepts
(d) the initial survey results.

There was time for questions after each presentation, followed by a longer discussion in sub-groups. Stakeholders attending the event included representatives from the Scottish Government Curriculum Division, the Scottish Qualifications Authority, Learning & Teaching Scotland, Education Authorities, Education Faculties in Universities, STEM Continuous Professional Development Providers, Skills Development Scotland and Scottish Engineering.

More details can be accessed through link WP2 in Section 5 below.

4.4 Project Newsletters and online Advisory Group

In response to the number of expressions of interest a series of Project Newsletters were produced to keep interested parties up to date with the project developments and related research and reports. Four newsletters were published; in August and November 2010, and in March and August 2011 (see link WP5 in Section 5 below).. 67 people signed up to receive the email alert that provides a brief summary of the items in each newsletter and the URL link to the newsletter itself. Over the span of the project no one unsubscribed:

An Advisory Forum , using Moodle software hosted at the University of Glasgow , was set up for a period from October 2010. This was arranged in response to the number of participants (24) who had expressed an interest in taking part in an online forum. The forum allowed members to: contribute their views to a range of on-line discussions; impart unique knowledge and skills to the development of the learning progressions; and receive regular updates and feedback, during the development of the science, technology and mathematics learning progressions and STEM Pathways. Membership was open to anyone with an interest in STEM education. This facility was closed when the project team were seconded to work on the Scottish Government project, when pressure of work compromised their ability to initiate good interactions and responses in the Moodle system. Nonetheless, on the basis of this limited experience it was concluded that this could provide a useful mechanism for ongoing interaction in future, dependent on the availability of a coordinator to seed the interaction, and to draw together conclusions.

On the other hand, the STEM-ED Scotland website was kept up to date with the latest information throughout the project lifetime, and email feedback was encouraged to a project dedicated email account.

4.5 Learning Pathways development

A two-day development event for the pathways was held on 29-30 October 2010. Subject specialists worked collaboratively (to make links across subjects and with numeracy and literacy) in development groups comprising of science, technology and mathematics teachers supported by the project team. The STEM pathways chosen for development were based on the findings from results of the online survey and the stakeholder meeting: These were: Measurement, Units & Scale; Changes of State; Mechanical Systems; and Modelling.

The three organisations involved in the project had identified a number of their members to take part, including five STTA members (secondary technology teachers), nine ASE members (primary and secondary science teachers, and university lecturers), six SMC members (secondary teachers and university academics), 1 member from Learning & Teaching Scotland and 3 primary teachers.

Two further events were held, one in May 2011 with seven secondary teachers (technology, science and mathematics) and the other in June 2011 with four primary teachers. These meetings helped to collate the remaining information required subsequently to complete and refine draft pathways into final form before the end of the project The pathways completed by this process were for Modelling in STEM, Mechanical Systems and Measurement, Units & Scale (for full details follow links LP1, LP3 and LP4 in Section 5 below)..

4.6 The Scottish Government project

In December 2010 the project team were seconded to undertake three months work for the Scottish Government. The work involved looking at developing two big ideas in science, without clear understanding of which young people could not be said to be developing scientific literacy. The remit was to describe a pathway illustrating how understanding of the core concepts, ideas and skills can be built up through education over the age range 3 - 18. The two "big ideas" selected were Energy Transformation and DNA and Inherited Characteristics. Through "storylines" these core ideas are used to communicate the importance of the relevant big ideas across science, and to show how they provide coherence within the sciences and connections across the curriculum. The pathways take full account of *Curriculum for Excellence* guidance.

This work contributed to the wider objectives of the 'Connecting It Up' project, whilst looking to extend the age range from third year in secondary (15 year olds) to the end of secondary (18 year olds). The work has involved consulting a range of teachers, academics in Higher and Further Education, organisations supporting teachers (including ITE) and industry contacts. Detailed feedback was obtained on the format of the draft pathways, and ideas were suggested and discussed on how best to use the pathways.

A Report "Learning Progressions in STEM 3-18," produced at the end of February 2011, contains the findings of the study and provides an analysis and an interim review of the development of the two learning progressions, and the data gathered during the consultations with science, technology and mathematics educators and professionals. This report can be downloaded through link WP4 in Section 5 below.

Following this Report (which referenced early draft descriptions of learning pathways on the two concept areas, an extensive programme of consultations was pursued, with teachers at all levels, through a series of sessions organised as Focus Groups. Feedback

from these (details also available through link WP4) provided a basis for producing finalised drafts. By this point a similar approach was being applied to these and to the other three pathways, and the final versions, under the titles Genetics & Inheritance, and Energy have been presented together with the three developed as described in 4.4 above. (For full details follow links LP2 and LP5 in Section 5 below.)

4.7 Engagement through other organisations

A presentation was made to the annual meeting of ASE (UK)'s National Advisers and Inspector Group for Science, under the title: "Stem through the Big Questions in science." A presentation and discussion session was also delivered with the Mathematics Advisers' Group for Scotland (comprising the relevant quality improvement managers from the local authority education service departments). An invitation was also taken up to present to the Scottish Government's Science & Engineering Education Advisory Group (SEEAG).

Contributions were made to the Scottish Mathematical Council's Conference, and also to a Workshop, and an article was published in their annual journal. Input was also made to the ASE (Scotland) Annual Conference.

4.8 End of Project Review Event

On 6 October 2011 a group of 21 participants was convened, to review the work completed in the project and to consider the best practicable strategy to support and encourage the application of the learning pathways through developments in curriculum planning and classroom practice.. Those present represented a broad range of perspectives, from primary and secondary schools, a college, two universities, local authority education services, Education Scotland and the SQA. This group included members of the project team, including senior members of Association for Science Education Scotland, the Scottish Mathematical Council and the Scottish Technology Teachers' Association. Some had contributed to earlier project discussions; others were being directly involved for the first time. The size of the invited group had been restrained to allow for effective and wide-ranging discussion.

In the view of the project team this was a very successful event. The discussions very heavily influenced the Project Conclusions described in Section 3 above. Most of the participants expressed their personal interest in contributing to follow up work.

5. Links to Project Outputs

All of the following can be downloaded from
http://www.gla.ac.uk/stem/routemapforstemeducation/

Principal Learning Pathways documents:

- **LP1** **M**odels in STEM
- **LP2** **Genetics & Inheritance**
- **LP3** **Measurement, Units & Scale**
- **LP4** **Mechanical Systems**
- **LP5** **Energy**

Principal working papers

WP1 Project overview briefing:
- briefing paper for stakeholders, May 2010
- short presentation introducing Review Event, October 2011

WP2 Stakeholder Meeting
- collected presentation slides
- paper giving overview of STEM skills

WP3 Analysis of Practitioner Survey (October 2010)

WP4 Learning Progressions 3-18: Report to Scottish Government (Feb 2011)
- the February 2011 Report
- analysis of the feedback gathered through Spring 2011

WP5 Tracking the Project - Newsletters