Firmer Foundations for Policy Making

The unrealised potential of 'engineering research' in education

Hugh Burkhardt
Hugh.Burkhardt@nottingham.ac.uk

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Executive summary

This paper outlines a development in evidence-based policy making that will yield outcomes closer to intentions in education and, perhaps, some other policy areas. For known or predictable challenges, the approach offers ministers a choice of well-developed solutions that have been shown to work well; these can replace often-hurried responses that are inevitably speculative and thus unreliable. The key new weapon is a programme of inexpensive, small-scale developments using the kind of "engineering research" methodology that is standard in successful research-based fields.

The problem that we address here is the common mismatch between policy intentions and the outcomes in practice. In doing so, we are aware of the pressures of public perception, time and money that policy makers face.

Evidence-based policy: the missing link. While the *diagnosis* of problems and the piloting of *treatments* is now research-based, the research-based *development* of those treatments is still rare. Education would gain from using the research-based approach to developing tools and processes that is used in more successful fields of innovation, such as medicine and engineering.

Rapid prototyping: exploratory small-scale developments A sensible approach to using the power of research-based methods starts with offering policy makers *options that have already been developed* so that they work well in meeting important goals. Prior development involves six aspects: *identifying areas of concern; generating ideas; small-scale development of tools and processes; evidence on the outcomes in circumstances broadly representative of those expected in large-scale use; guidance to policy makers on the various choices; lessons for future work in the area*. To give policy makers real choices means exploring the full range of possibilities. Such work needs teams with *diverse skills* in research-based design and development, working with an evaluation and policy making infrastructure.

Building an improvement bank Innovations that work well take time to develop. The research-based process, standard in more mature fields, uses prior research and exceptional design skills to produce prototypes. Systematic development through iterative trialling, feedback and revision then refines them until they work well. There will still be unexpected "events" that need an improvised response but they can be handled within a stream of steady progress.

Building long-term progress on short-term successes Strategy must reconcile the decade timescale of all substantial educational or social improvements with the political need for bankable year-by-year successes. Well-designed incremental improvement not only achieves this; it also allows policy makers to optimize the pace of change. This approach allows regular announcements of new initiatives designed to tackle specific problems as part of a coherent long-term strategy. Prior development of prototypes makes it much more likely that subsequent evaluation will find successful outcomes.

Build human capital The high-level skills needed for this programme are in short supply in this country. If the approach proves promising, this stock of human capital will need to be developed. This takes time but much could be achieved over a decade of steadily increasing successes (The private sector in education does not, and cannot in the medium term, provide a 'market' that achieves this)

Cost-benefit analysis This approach should be tried first on a small-scale. Careful evaluation of costs and outcomes will provide strategic policy makers with the evidence on its worth. They can then decide whether and how fast to expand it.

[1] Hugh Burkhardt and the MARS/Shell Centre teams at Nottingham, Berkeley and Michigan State. Contact: *Hugh.Burkhardt@nottingham.ac.uk*

1. The problem and the way forward

This paper looks from a strategic perspective at the Government's approach to evidence-based policy making. It compares it to research-based methodologies in fields where successful innovation is well established, particularly medicine and industry, to those in education[2].

The outcomes in practice of government initiatives are often far from the intentions.

We assume this is common ground; if not, it is easy to find multiple examples. In this paper we shall use one specific policy area, "functional mathematics", to clarify the assertions we make[3]. If asked, we shall be happy in a longer version of this paper to set out some of the substantial body of evidence.

On functional mathematics, it is sufficient to note that this was a major point in Prime Minister James *Callaghan's 1976 speech* (Google italics) that led to the Cockcroft Report. It was again a major driver of the 1987 National Curriculum reform. It is again an explicit goal of current Government policy; again, it looks inadequately engineered.

Each initiative expressed the same concern – that many people are unable to use in their adult lives the mathematics they were taught at school, despite the time and emphasis given to the subject throughout education up to age 16. Yet it remains true. Indeed, most adults use *none* of the mathematics they were first taught after the age of 11, though it could enable them to understand the world better, and make better decisions in life and work. (This is true from the unskilled worker to the typical humanities graduate)

The theme of this paper is that such continuing failure is not inevitable – that *more powerful methods of design and development*, of a kind standard in other research-based fields, could avoid this mismatch between intentions and outcomes. If adopted, this will yield improvements both in informing policy formation and the 'engineering' of the implementation process.

2. Evidence-based policy: the missing link

The Government is committed to evidence-based policy formation. Indeed, two elements in the standard innovation cycle are now firmly established as part of government policy making. Using medical nomenclature, they are:

Diagnosis: insight-focused research regularly provides policy makers with diagnostic information on the strengths and weaknesses of current practice in many fields, including education.

Phase 3 trials: Piloting of treatments before implementation for evidence on outcomes is Government policy, set out in the Green Book.

However, *the research-based link between these two is too-often missing* – it is:

Design and development of initiatives using research-based methods.

This is analogous to Phases 1 and 2 of the development of treatments in medicine – the initial small scale explorations leading, in selected successful cases, to their careful systematic development.

The design of innovations in education is still usually left to the traditional approach, which is *purely craft-based*. Groups of expert practitioners are asked to design an innovation, extrapolating from their successful experience to the new area in question. Extrapolation is a notoriously unreliable process and the usual limited impact of innovative programs, together with their unintended consequences, reflects this.

In contrast, other fields like energy policy, defense and health use the research-based methodologies of engineering and medicine to develop relatively reliable solutions to

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[2] It has not escaped our notice that these strategic points may apply to other fields of policy where there is a significant research and development base.

[3] Appendix B links the general argument to current Functional Mathematics initiatives.

offer to policy makers, and to support the implementation of the policy choices they make. Research-based design and development involves, sequentially:

- **review** of research, of craft-based knowledge, and of earlier innovations;
- **design**, imaginatively exploring a broad range of design possibilities;
- **development** through an iterative process of feedback from small-scale trials;

sifting out at each stage those candidates and aspects that prove less promising.

Piloting in representative circumstances is the *final* step before large-scale implementation. Its usual role is a summative validation of the initiative, rather than providing formative and developmental feedback. The *prior* phases of research-based development, too-often by-passed in education, are where the product is refined through rich and detailed feedback, its quality and robustness enhanced, and unintended side-effects discovered.

Is education as a field capable of delivering this research-based engineering approach?

Every research-based field has developed from its craft-based origins. A century ago, medicine was largely craft-based. While several centuries of insight-focused science research had improved understanding of the body and its ills, practitioners still used much the same methods passed on by skilled forbears in their training. There were some important research-based aspects of treatment – for example, those arising from Pasteur's work that developed the germ theory of disease, and thus aseptic practices in surgery[4]. Purely craft-based practice predominated, leeches and all, much as in "alternative medicine" today. The doctor had only a handful of effective drugs – apart from anaesthetics, aspirin was, perhaps, the most useful! There was little systematic design and development in medicine, and little progress. We do not need to review the progress over the last century during which medicine has become substantially research-based – but not entirely. There remain many areas, like the common cold and moderate low back pain, where traditional treatments have not yet been improved upon. Those areas become fewer with time as conditions (cancer, for example) become treatable by research-based methods. Further, we now have a system of research-based evaluation, integrated by NICE, of the effectiveness and, more controversially, cost-effectiveness of different treatments[5].

Education is still at a relatively early stage in its development as a research-based field but, worldwide, progress is steady. There are by now plenty of examples in this country, particularly in science and mathematics education, that illustrate the superiority of the *engineering research approach* – imaginative design and systematic development. It is time to explore further the contributions it can make to policy formation and successful implementation along the lines suggested here.

Even when research-based methods have been used in education, notably in test development, the commissioning specification has often been too narrow, excluding design solutions that would allow the realisation of the policy goals. We address this problem, too, in what follows.

3. Rapid prototyping: exploratory small-scale developments

A sensible approach to using the power of research-based design methods starts with offering policy makers *options that have already been developed so that they work well* in meeting important goals. Such prior development involves four steps: identify areas of concern; seek out ideas; select and fund some parallel small-scale developments of tools and processes; evaluate their strengths and weaknesses. Again, this *thinking*

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[4] *Pasteur's Quadrant* (D. E. Stokes, Washington, DC: Brookings Institution 1997) discusses the relationship between pure insight-focused and applied impact-focused research.

[5] The development of engineering from the 18th century on can be similarly traced, moving rapidly from a largely craft-based to a research-based field until, now, one can design an aircraft on a computer and it will fly. They still develop the design through extensive well-instrumented test flights. It is then evaluated by the airworthiness authorities and the airlines.

ahead approach is standard for innovation in other research-led fields. It does not mean that ministers will no longer need to react to "events" with rapidly produced responses but it does enable these to be carried along in a stream of successful improvements addressing important issues.

If policy makers are to be given the full range of choices, this process needs to be *initially divergent*, exploring a wide range of possibilities, then seeing how far each can be realised. Hence the need for several parallel projects, working in creative competition. These must provide: tools, and processes for their use; evidence on the outcomes in circumstances broadly representative of those expected in large-scale use; guidance to policy makers on the various choices; lessons for future work in the area.

Such work needs teams with *diverse* skills and experience in research-based design and development, working within an evaluation and policy-making infrastructure. What are the challenges of the four phases set out above? How can government best direct each stage?

Areas of concern in education are not hard to find. There is broad longstanding agreement on many specific problems[6]. While Government will want from time to time to focus on specific areas, it should be open to suggestions from outside, particularly when they are linked to

Generating promising ideas for ways of achieving improvement in specific areas of concern. This is at the heart of the research-based process. It is best achieved by establishing ongoing dialogue within small communities of those active in development of this kind, in the area and beyond. To encourage creative divergence, the dialogue should be supported by, but not dominated by government. The expected outcome is a list of avenues worth exploring, estimates of costing and some idea of the likelihood of success. A formal invitation to submit full proposals is the *end* rather than the beginning of this process, leading to a group of linked

Small-scale parallel developments of 'treatments', including tools and processes for their use, will provide the specific information that policy makers need to make sound decisions. The selection of projects for this phase should reflect both the promise of the ideas and the track record of the team, usually mixing 'safe' choices with some that are more speculative. At the end of each project, the key questions it must answer are:

- What is the treatment?
- What are the outcomes in reasonably realistic circumstances?
- What are the requirements of personnel, training, and other resources that underpin those outcomes?
- What has been learnt that should guide future development?
- What further evaluation and other research is needed to carry things forward?

Independent comparative evaluation of these 'treatments' should use an agreed methodology *covering all the goals*, linked to the formative evaluation in each development.

With this information, policy makers are equipped to choose initiatives that work well for piloting and, ultimately, large-scale implementation – narrowing the gap between intentions and outcomes.

What do we mean here by "small scale"? That will, of course, depend on the system concerned but, after informal trials, 'hands-off trials' with samples of 5-10 systems are enough to separate the generic from the idiosyncratic outcomes. For changes at classroom level, this means 5-10 classrooms, varied within the target group. For school organizational reforms, 5-10 schools is a suitable sample size for "hands off" trials.

[6] Functionality with mathematics is one such area, currently suffering a single-track approach.

The current Bowland/DCSF Case Study Initiative in Mathematics has many of the features suggested here[7]. This is not an isolated example. Over the last 40 years, the influence of the various projects of the Nuffield Foundation in improving STEM education compares favourably with that of successive governments. Is there any compelling reason why Government cannot adopt this approach, prior to and informing decisions on large-scale implementation?

4. Building an improvement bank

The logic of this approach is to be ahead of government's need for new initiatives. A 'bank' of well-developed treatments that have been shown to lead to specific improvements gives policy makers the flexibility to choose initiatives that reflect their priorities and their perceptions of current and future needs.

This improvement bank need not start from scratch. There is a substantial body of well-developed tools from recent decades that are directly relevant to current challenges. These are resources that, through careful selection and adaptation to current needs, can give an improvement bank a flying start. To review previous work with care, and to build from it, is a standard practice in other fields; it is currently neglected in education.

5. Building long-term progress on short-term successes

The engineering of models of change is too broad a topic for this paper but a few comments are in order. A successful government strategy must reconcile the decade timescale of all substantial educational improvements with the political need for bankable year-by-year successes. There is no well-established model for achieving this but there are some results.

Policy makers often tackle problems with broad global changes (reorganizations[8], reducing class sizes, …..). These tend to be both costly and distracting, yet with limited effect on learning outcomes.

There is a recognition that, if professionals are to change well-grooved patterns of practice, *pressure* is necessary. In education, high-stakes tests are a convenient and powerful tool for this. However, the tests are too-often poorly engineered. For example, if the tests are not balanced across the learning goals, teachers, understandably, do not teach for those goals that are not assessed. (see e.g. OFSTED 2006) "Simple tests", while popular with different groups for different reasons, thus produce impoverished learning. Such unintended consequences are characteristic of poor engineering.

Further, *pressure* is not enough. Those that are pressured to change, must be given the *support* that actually enables them to do so – a design and development challenge.

It is often assumed that the private sector will provide the necessary resources; indeed, it will. However, in education the private sector does not do research-based development, as it does in, say, medicine and engineering. Why should it? It is more costly and there is no systematic evaluation of products. This is characteristic of fields at this stage of development – medicine, too, began to move forward with publicly funded research, on which progress still heavily depends.

There is an alternative approach that has many advantages – a coherent programme of incremental improvement, with well-engineered *pressure* and *support* for each step. This reconciles the mismatched timescales of educational improvement and political need. It allows policy makers to optimize the pace of change, to match pace to resources and to avoid the "system shock" that so often undermines "Big Bang"

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[7] Appendix B compares the approaches in this initiative to that for the Government's development of tests in functional mathematics; they have similar goals but different approaches.

[8] Reorganisations often divert attention and energy from direct improvements in teaching and learning for an extended period. Their cost-benefit balance needs careful investigation.

improvements[9]. It provides a 'learning system', modifying the programme as it goes along in the light of feedback from the field on earlier steps. It allows year-by-year announcements of new initiatives designed to tackle specific problems as part of a coherent long-term strategy. The prior development approach outlined above greatly increases the chance that evaluation will support later announcements of successful outcomes.

It is worth exploring this apparently-more-modest approach, if only as a complement to occasional major reform efforts. There is evidence that a sequence of small-scale changes, accumulating over several years within a long-term strategy, can lead to major improvements at modest cost[10]. Functional mathematics is a suitable area to try this.

6. Building human capital

The high-level skills needed for a research-based approach are in short supply in this country. Professional educational design and development teams have no established role in educational planning. Each such team must survive on a sequence of short-term projects, usually arising as an adjunct to admirable but incoherent policy initiatives. It is no wonder that few have survived.

This contrasts with the situation in other industries, where the need for sustaining expertise in the medium-term is recognised, and in education in some other countries. The Netherlands is a good example. There the Freudenthal Institute, with about 70 staff, has received ongoing support from the government to provide a research and development base in mathematics education[11]. The Netherlands' scores in PISA and other international comparisons reflect this, as does their outstanding reputation around the world for turning research *insights* into *impact* on practice – the role and *raison d'etre* of engineering research. In the US, a handful of centres with high-quality design and development teams survive on the multiplicity of initiatives arising from the many school systems there.

In this country, most development project teams in education are built *ad hoc* with people from teaching, teacher education and/or conventional research – to which they return when the project is over. Such practitioners have related but very different skills from those needed for the design and development of effective tools and processes for others to use. (GPs do not develop new medicines). These skills cannot be quickly acquired; as in any highly skilled occupation, they develop over a period of years and the best are highly gifted to begin with.

If the approach outlined here proves promising, this stock of human capital will need to be gradually and coherently developed. This will take time but much could be achieved over a decade, with successful impact and resources growing together. If that is to happen, government must take the lead.

7. Cost-benefit analysis

This approach should be tried first on a small-scale – indeed, that is inevitable given the small number of experienced groups that have the skills to show its potential. Careful evaluation of costs and outcomes will provide strategic policy makers with the evidence on its worth. They can then decide whether and how fast to expand it, and in what fields.

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[9] Indeed, experience shows that teachers and other professionals actually *enjoy* regular, moderate doses of profound change.

[10] Indeed, if a well-engineered innovation tackles a *new* learning goal that is important but neglected, success can be almost guaranteed (The "switch on effect")

[11] For comparison, the Shell Centre for Mathematical Education was founded about the same time for similar purposes and has a high international reputation. It is one-tenth the size and has no ongoing funding; its 40-year survival is due to a mixture of quality, cunning and, particularly, luck.

On outcomes, we have referred indirectly to evaluation throughout this paper – formative evaluation is central to research-based development, providing the feedback that informs the refinement of the products. The importance of evaluation in research-based policy is equally well-recognised. However, if it is to play the roles that are needed, it needs to be expanded and re-balanced to provide the information that is needed to guide both policy and practice. How this can best be done needs a separate paper.

Here we shall only note that we don't have NICE, or even "Which?", in education. Indeed, there is no serious evaluation of the tools and processes that are central to our education system. New teaching materials are reviewed in the TES based purely on inspection, with no empirical evidence on what happens in classrooms with what kinds of teachers and pupils. The tests that are the main measures of success are subject to no research-based evaluation on how well they assess the various learning objectives of the curriculum[12]; only issues of fairness and comparability receive attention.

On costs, it is important to recognize the scale of cost of the school system, around £35 billion per year, and where these costs arise – notably in teachers salaries, where the total is inversely proportional to average class size. This is the denominator against which expenditure on improvement should be measured.

Organisations that are serious about the need for research-based improvement typically invest 5-15% of turnover in R&D – roughly 80% of it on engineering research.

If growing to 1% (£350 million a year) were regarded as a reasonable target for investment in educational R&D, that investment is equivalent to[13] decreasing the average class size by less than half a student – a negligible gain[14]. That level would represent over 3000 developers, playing various roles across the needs of the school system. It will take more than a decade to develop the skilled human capital implied.

In summary, any expenditure must be compared with the improvement in outcomes. If adopted, the approach suggested here must show improvements that more than match the investment. There are good evidence-based reasons to believe that, if well-directed, it will do far better than that.

Acknowledgement: While this paper is an outcome of discussions over many years' work in this area, particularly with those listed Appendix C, the contents are my responsibility.

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[12] OFSTED has remarked on the gross distortions the narrowness of current tests has produced in mathematics classrooms, most teaching being confined to the range of tasks the tests contain. Teachers have long seen the tests as defining the targets that Government sets them.

[13] Ignoring other changes that may happen. This simple 'comparisonr' argument seems to us the clearest way to cost any educational expenditure.

[14] The Japanese teach classes of 50 with great success. They spend a great deal more on teacher support.

Appendix A: Planning policy initiatives: questions to ask

Pursuing the following questions[15] will help make the outcomes in practice close to the policy intentions:

The level of challenge

- Is this a routine development or are there design problems to be solved[16]*? If the latter, small-scale design studies will inform the main commissioning.*

Prototyping

- Have we involved a wide enough range of design teams to reveal the full range of possibilities? For each:

  What is their track record? Is their methodology research-based? How far is this problem beyond their prior experience?
- Have we made the design brief open enough to cover the full range of possibilities? Have we imposed unnecessary constraints?

After they have reported, ask of each proposal:

- Does this proposal address all the policy goals in a balanced way?
- Is the balance of pressure and support credible? (Do they provide any evidence that the support will enable the target groups to respond successfully to the pressure, i.e. to meet the policy's goals for them)
- Can their informed advice on schedule and budget be accommodated?

Commissioning

- Does this brief incorporate the opportunities revealed by the preliminary studies?
- Is there reason to believe that the design and development capability is available?

  Important aspects of capability are:
  - strong research background;
  - track record of imaginative and effective design in this field;
  - systematic development methodology – iterative trialling with rich feedback and evidence-informed revision
  - track record of delivering high-quality products on time and within budget.
- Does the team behind the selected proposal have that capability? If not, can it be augmented to fill the gaps without undermining its effectiveness?
- Is the schedule well-balanced in terms of the work to be done in each stage? Is time being wasted through slow responses from the client-funder?

Main design and development process

- Is the process of regular contact with the design team well-established? Does it involve staff of the client-funder who have deep knowledge of the area?
- Is the project processes reasonably close to those planned? Have departures been explained, understood and agreed?

Review and capture what has been learnt

- What were the differences between the project intentions and what happened?
- Could these have been, indeed were these, predicted?
- What lessons are there for future projects?
- What further studies would help future planning?

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[15] This is based on standard processes for the design and development of innovative products and processes in successful fields.

[16] Design challenges are regularly underestimated by Government, which assumes that "professionals" know what will work, however far outside their experience it may be.

Appendix B: Two approaches to mathematics that is functional

Government policy is to make "functional mathematics" part of the national curriculum. Currently there are two substantial initiatives. QCA is overseeing the development of tests, now in the 'pilot' phase, by groups linked to awarding bodies. The Bowland Trust, with support from DCSF, is funding the development of "case studies" – 3-5 lesson teaching units, with an associated professional development package, and related assessment. The table gives a brief comparison of methodologies.

Functional Mathematics Tests	Bowland/DCSF Case Studies[17]
Area of concern Many adults are unable to use the mathematics they were taught at school in tackling problems in their life and work. Research shows these skills can be taught and tested; neither of these is happening in KS tests or GCSE	**Area of concern** "…….thinking, reasoning and problem solving skills in KS3 pupils" in situations from outside mathematics. This reflects the focus in the new programmes of study on processes: *representing, analyzing, interpreting,….* currently "rather hidden" in many classrooms, and in the tests
Generating ideas *No open search for ideas to guide ITT Challenge seen as routine?* ITT specifies complete packages with many constraints on their design. Selected teams have similar backgrounds (strong in test delivery in other areas; none in innovative research-based development in this area)	**Generating ideas** Open invitation to submit ideas as brief outlines, based on a given set of broad principles >> selection >> Funded invitations to teams with diverse experience to develop full design and development proposals (@ <£2,000 each) >> selection >>
Prototype developments *No Phase 1 or 2 development.* *No cross fertilisation of ideas.*	**Prototype developments** Diverse teams commissioned to develop specified units over one year (@ <£50,000 each) Opportunities for cross-fertilisation, while preserving diversity.
Evaluation Pilots of (parallel) packages Independent evaluation? Unclear. Perhaps "consultation" for a short period >> ministerial decision on implementation. *No independent analyses of how far the tests assess the kind of performance that was the focus of the initial concern*	**Evaluation** Formative evaluation by teams as part of the development process. Independent evaluation in some depth by a research organisation >>selection of units for implementation

[17] The director of this enterprise, Quentin Thompson, is familiar with the workings of government. He previously worked in the Cabinet Office.

Appendix C: Background of the team members

Hugh Burkhardt has been at the Shell Centre for Mathematical Education at the University of Nottingham since 1976, as Director until 1992. Since then he has led a series of international projects including: *World Class Arena for Problem Solving* (QCA); *Balanced Assessment in Mathematics* (US NSF) and its *Mathematics Assessment Resource Service*, MARS; the *Toolkit for Change Agents* (US NSF); and the team's work for the current Boland/DCSF Mathematics Initiative.

Professor Burkhardt takes an 'engineering' view of educational research and development - that it is about systematic design and development to make a complex system work better, with theory as a guide and empirical evidence the ultimate arbiter. His core interest is in the dynamics of curriculum change. He sees assessment as one important 'tool for change' among the many that are needed to help achieve some resemblance between goals of policy and outcomes in practice. His other interests include making mathematics more functional for everyone. He remains occasionally active in theoretical elementary particle physics.

He is Chair of ISDDE, the *International Society for Design and Development in Education*, which works to raise standards in this area.

Advisers include:

Alan Schoenfeld, Elizabeth and Edward Conner Professor of Education at Berkeley, has been vice president of the US National Academy of Education and president of the American Educational Research Association. He is a senior advisor to the Education and Human Resources Division of the National Science Foundation, and was Senior Content Advisor for Mathematics to the US Government's "What Works Clearinghouse".

Malcolm Swan has been a leading designer in the Shell Centre since 1979, when he joined the staff in Mathematics Education at the University of Nottingham. His research interests lie in the design of teaching, assessment and professional development, particularly the design of situations which foster reflection, discussion and metacognitive activity, and the design of assessment methods that have a positive backwash effect on teaching and learning. For five years he was Chief Examiner at NEAB (AQA). He has worked on internationally funded research and development projects concerning diagnostic teaching, reflection and metacognition and on problem solving assessment. He is interested in teacher development and has produced resources for the professional development of teachers. The outcomes of this research programme are published as *Collaborative Learning in Mathematics: A Challenge to our Beliefs and Practices.* More recently, Malcolm has been working with DfES/DCSF, designing new teaching strategies for low attaining post-16 students and evaluating their impact on student learning and on the beliefs and practices of experienced teachers. The materials from this work, *Improving Learning in Mathematics,* were commended by OFSTED and sent by Government to all schools, colleges and other educational institutions. He is a lead designer for the Bowland Initiative.

Daniel Pead is Technical Director of the Shell Centre and MARS, leading all the ICT work of the team. Senior Research Fellow in the University of Nottingham, he managed the work of the team for the UK Qualifications and Curriculum Authority *World Class Tests/Arena* project as well as designing its computer-based tasks and learning materials. Currently he is researching a range of options for the computer-based assessment of Mathematics . He plays a leading role in the IT design for the Bowland initiative. Earlier he helped design and programmed the videodisc-based *World of Number* materials for the UK National Curriculum Council, which was awarded a Gold Medal and, for the independent charity Population Concern, a CD-ROM with a wealth of resource material on the complex issues surrounding population growth, economic development, ecology and other related issues. That also received an award.

He is Secretary of ISDDE.